HYDROLOGIC DESIGN AND ANALYSIS COMPUTER PROGRAMS

User Reference

Department of the Interior
Bureau of Land Management
Denver Service Center 1984

IN REPLY REFER TO

7200 (D-471)

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
DENVER SERVICE CENTER
DENVER FEDERAL CENTER, BUILDING 50
DENVER, COLORADO 80225

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Information Bulletin No. DSC-85-44

To: All Field Officials

From: Service Center Director

DEC 31 1984

Subject: Hydrology Computer Programs

The enclosed user reference was prepared for seven hydrologic design and analysis computer programs which have been written for the BLM Honeywell DPS-8 Computer, and its predecessor, a Honeywell Series 60 (Level 66)/ 6000 computer. Program background and computational procedures, including program uses and limitations, are described. A worked example problem in the form of a sample run is provided. An abbreviated summary of each program is provided on pages i-iii. If you need to make modifications to make the program(s) more suitable to your individual requirements, all programs can be copied to your own User Master Catalog (UMC). The programs are designed to be self-prompting and easy-to-use.

Additional surface water and ground water computer programs are available and are described in the literature in the front cover pocket.

If you require additional copies of the user reference, or have questions regarding the application of the programs, please contact Bill Jackson, Division of Resource Systems, D-470, (303) 236-0148, FTS 776-0148.

Delmar D. Vail

1 Enclosure
Encl. 1 - User Reference (84 pp.)

Distribution
WO (200) - 1
WO (201) - 1
WO (220) - 1
D-245A - 1
D-400 - 1
D-470 - 2

OTHER INTERACTIVE WATER HYDROLOGY COMPUTER PROGRAMS

CURRENTLY AVAILABLE ON THE BLM HONEYWELL DPS-8 COMPUTER

PROGRAM: CHANL and MCHANL (metric version) : Channel Geometry

ACCESS: * FRN A249/CHANL, R

DESCRIPTION: These programs reduce and analyse stream channel cross-section survey data collected by either a rod and level survey or a sag tape survey. Data may be entered from the keyboard or a file. Cross sections are plotted on X-Y coordinates and discharge rating curves are developed using Manning's equation given a user-supplied value for Manning's "n". Output tables also include values for average flow velocity (for each discharge increment), cross-section area, wetted perimeter, and hydraulic radius.

PROGRAM: KAY (SCS Curve Number Runoff Model)

ACCESS: * BRN A249/KAY, R

DESCRIPTION: This program is a storm runoff model based on SCS Curve Number methods. The program calculates runoff volume and develops a synthetic hydrograph for a user-defined rainfall depth, duration, and distribution. Watershed input parameters include area, average land slope, channel length, and Curve Number. Single or multiple small watersheds may be analysed concurrently, although there are no provisions for channel routing (see "FLOOD" program for flood routing analyses).

HYDROLOGIC DESIGN AND ANALYSIS PROGRAMS WRITTEN IN BASIC

FOR THE

HONEYWELL SERIES 60(LEVEL 66)/6000 COMPUTER

Submitted To

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Division of Resource Systems
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By

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FOREWORD

This volume provides user guidance in the operation of seven hydrologic design and analysis computer programs which have been written for the Bureau of Land Management's (BLM) Honeywell Series 60 (Level 66)/6000 computer. Program background and computational procedures are described, including program uses and limitations. A worked example problem in the form of a sample run is provided. The programs are written in BASIC. They are designed to be completely interactive and easy to use.

The objective in having these programs written is to make commonly used but computationally cumbersome analytical procedures readily available to field office specialists working on problems of hydrologic design and analysis. The computational procedures were originally developed for handheld programmable calculators. Programs 1-4 were derived in part from calculator programs prepared for the USDI Office of Surface Mining, Region V (Report H-D3004/030-81-1029F). "Small Calculator Programs for Analysis of Waterbeds and River Systems", by the Colorado State University Research Institute, served as a reference for Programs 5 and 6. Program 7 was derived in part from a program developed for Hewlett-Packard 67 calculator by L. Busack, Monaco, PA.

This user guide is prepared in loose-leaf format to provide the user maximum flexibility in maintaining and expanding a useful library of hydrology programs.

Any questions should be directed to the Division of Resource Systems, D-471, (303) 236-0170, FTS 776-0170.

Denver Service Center
September 1984

TABLE OF CONTENTS

PROGRAM SUMMARIES

PROGRAM: FLOOD (Flood Routing, Dam Breach Analysis)
ACCESS: *BRN A403/FLOOD, R
DESCRIPTION: This program routes a set of inflow hydrographs through a multiple channel and/or reservoir system using the Muskingam and Puls methods. The program also provides the option of analyzing expected flows due to a dam breach by either overtopping or piping. Up to 100 channel and/or reservoir segments can be routed, up to 10 of which can be reservoirs. Each reservoir can have up to 10 arbitrary increasing stage/discharge/storage values. Up to five segments can be confluent into a single segment. Inflow hydrographs to headwater segments can be input from the keyboard or from a previously saved data file. Inflow hydrographs must define flows for each time step.

The dam breach analysis requires that water levels and dimensions of the breach be specified as per a diagram which appears on the screen. The dam breach option can also be used to generate stage/discharge/storage values for input to the routing routine.

PROGRAM: BACKH2O (Backwater Curve)
ACCESS: *BRN A403/BACKH2O, R
DESCRIPTION: This program uses the direct step method to determine a water surface profile and flow velocities under gradually varied flow conditions for a fixed rate of flow in a trapezoidal, rectangular, or triangular channel by the standard step method.

The program also provides the capability to determine normal flow depth or critical flow depth for a given channel cross section, Manning's n, and flowrate. These depths can then be used as starting or ending points for determining downstream or upstream water surface profiles and flow velocities. This program will also generate a water surface profile plot when requested by the user.

PROGRAM: PEARSON (Log Pearson Type III Flood Analysis)
ACCESS: *BRN A403/PEARSON, R
DESCRIPTION: This program fits a series of flow events such as peak annual flows to a Log Pearson Type III distribution. This distribution is commonly used to predict flood recurrence intervals. Initial data input for a given gaging station is the number of

measured peak flows and the amount of each flow in cubic feet per second (CFS). If flow data for a particular gaging station has been previously analyzed, and the resulting output saved to a disk file, the disk file may be called up at the user's request in order to avoid re-inputting all of the flow amounts. Previously entered flows may also be edited and added to during later program runs. The program is limited to 200 flows per gaging station. The program begins by asking for the name of the file the output is to be written to. If an output file has been previously generated, the same file name may be used, or a different file name may be used to separate the results.

PROGRAM: USLE (Universal Soil Loss Equation)
ACCESS: *BRN A403/USLE, R
DESCRIPTION: The program uses the Universal Soil Loss Equation (USLE) to estimate soil loss from a given acreage of land. The USLE is an empirically developed formula intended to estimate soil loss on agricultural lands. The USLE only accounts for sheet and rill erosion. No erosion from gullying is considered. In the western U.S., gully erosion is often the principal source of sediment. Thus, the USLE may not represent a comprehensive total of erosion from an area in the western U.S. The USLE only considers average erosion, not the sediment delivery ratio to a stream channel. When applying the USLE to estimate sediment impacts on surface water quality, the total erosion computed by the USLE must be adjusted with the appropriate sediment delivery ratio. This program allows the option of a sediment delivery ratio to be input after the amount of average soil erosion has been calculated.

PROGRAM: GREEN (Green and Ampt Infiltration Analysis)
ACCESS: *BRN A403/GREEN, R
DESCRIPTION: This program uses the Green - Ampt infiltration equation to compute incremental and cumulative excess rainfall and infiltration volume. The program implements the homogeneous soil version for time varying rainfall as represented by a hyetograph. Required input includes the average suction head and the conductivity in the wetted zone. The rainfall intensity hyetograph may be input from the keyboard or from a previously generated data file.

PROGRAM: MPM (Meyer-Peter, Muller Bedload Transport Equation)
ACCESS: *BRN A403/MPM, R
DESCRIPTION: This program uses the Meyer-Peter, Muller equation to compute the bedload transport rate for a given sediment size range. The program also computes the suspended sediment transport rate using a numerical integration of an approach developed by Einstein. Program output includes bedload and suspended load for each size range input as well as the total transport rate for all size ranges input (for a given rate of flow). Required input includes the Darcy-Weisbach friction factor, kinematic viscosity, the flow velocity, the width of flow, channel slope, and depth of flow.

PROGRAM: POND (Detention Pond Design)
ACCESS: *BRN A403/POND, R
DESCRIPTION: This program calculates the pond volume required to detain the excess runoff occuring because of a change in basin runoff conditions. Detention pond volume is calculated using estimated peak inflow, desired peak outflow, and the expected excess runoff volume. Excess runoff volume can either be input directly (pre- and post rainfall excess) or can be calculated using SCS methods (pre- and post Curve Numbers). The program will also calculate expected peak outflow from a detention pond given rainfall excess, storage capacity, and peak inflow.

1. FLOOD ROUTING AND DAM BREACH ANALYSIS

I. Introduction

Streamflow routing is the technique used in hydrology to compute the effect of channel storage on the shape and movement of a flood wave (1). The same principles also apply to computing the effect of reservoir storage on the shape of a flood wave. This program routes a flow through a series of channels and reservoirs using the Muskingum method for the channel segments and the Puls procedure for the reservoir segments. The progam also provides a subroutine which uses standard weir and orifice formulas for the analysis of expected flows due to a dam breach by either overtopping or piping.

II. Program Theory

The Puls and Muskingum methods are the most-employed hydrologic flood routing techniques for reservoirs and channels. Both are traditionally solved in tabular form with graphical aids and both are derived from conservation of flow over discrete time steps (2). The Puls method assumes a constant discharge-storage relationship for the given reservoir being assessed. For a given time interval, the change in storage for a reservoir segment is the difference between inflow and outflow:

$$I - O = \Delta S \; , \qquad [1\text{-}1]$$

or, if expressed in finite time intervals,

$$1/2(I_1 + I_2)\,\Delta t - 1/2(O_1 + O_2)\,\Delta t = S_2 - S_1 \; , \qquad [1\text{-}2]$$

where the subscripts indicate the routing periods, and I, O, and S are instantaneous values of inflow, outflow, and storage, respectively, at the beginning of the routing periods indicated (1). The equation can be arranged so that all of the known values are on the left:

$$1/2(I_1 + I_2)\,\Delta t + S_1 - 1/2\,O_1\,\Delta t = S_2 + 1/2\,O_2\,\Delta t. \qquad [1\text{-}3]$$

During routing the known values are substituted into the above equation to obtain $S_2 + 1/2\,O_2\,\Delta t$. O_2 can then be obtained from the relationship between O_2 and $S_2 + 1/2\,O_2\,\Delta t$ using the discharge-storage curve (1).

The Muskingum method was developed in conjunction with the Muskingam Conservancy District Flood-Control Project of the U.S. Army Corps of Engineers in 1934-35 (4). The method utilizes the concept of wedge and prism storage. When steady flow exists, storage volume can be related to outflow by a simple linear function. During the advance of a flood wave steady flow does not exist (i.e., inflow exceeds outflow) and a wedge of storage is produced. During the recession of a flood wave, outflow exceeds

inflow and a negative wedge storage results. In the Muskingam method, the wedge is related to the difference between instantaneous values of inflow and outflow. The method also accounts for the remaining channel storage, termed prism storage. The total storage then becomes:

$$S = KO + KX(I - O). \qquad [1\text{-}4]$$

This is the Muskingam equation where prism storage is represented by the first expression (KO) and wedge storage is represented by the second expression (KX(I-O)). In these expressions K is a coefficient termed the storage time constant, and X is a weighting factor between 0 and 0.5 (typically 0.2 - 0.3).

Using the symbols as defined above for the Puls method, the Muskingam equation can be written as:

$$S_2 - S_1 = K[X(I_2 - I_1) + (1 - X)(O_2 - O_1)]. \qquad [1\text{-}5]$$

Combining this equation with Eq. 1-2 and simplifying,

$$O_2 = C_1'I_2 + C_2'I_1 + C_3'O_1 \qquad [1\text{-}6]$$

where,

$$C_1' = \frac{\Delta t - 2KX}{2K(1 - X) + \Delta t} \qquad [1\text{-}7]$$

$$C_2' = \frac{\Delta t + 2KX}{2K(1 - X) + \Delta t} \qquad [1\text{-}8]$$

and,

$$C_3' = \frac{2K(1 - X) - \Delta t}{2K(1 - X) + \Delta t} \quad (\underline{1}). \qquad [1\text{-}9]$$

K and X are usually estimated through a plotting analysis of known flood hydrographs. Sometimes K is estimated as the travel time through a reach. Discussions of how these parameters may be estimated can be found in *Handbook of Applied Hydrology* (1), and *Hydrology for Engineers* (3). The flood routing program is based in large part on the algorithms supplied in *Flood Routing on a Small Computer* (2). The form in which the program is written requires a minimum amount of memory because overlaying techniques are incorporated to utilize the same array variables repeatedly to store different data. The limitations on the number of time steps and channel and reservoir segments which can treated for a single problem can be increased by adjusting the (DIM)ension statements for these array variables in the program source code if the user so desires. For further information on how the Muskingam and Puls methods are implemented in the program the user should consult the above referenced article.

The weir and orifice equations used for the dam breach subroutine in the program are as follows:

Rectangular Weir

$$Q = 3.075\ L\ D^{1.5} \qquad [1\text{-}10]$$

Triangular Weir

$$Q = 1.156\ L\ D^{1.5} \qquad [1\text{-}11]$$

Parabolic Weir

$$Q = [0.809+3.66(L/2D)^{2}-1.02(L/2D)^{4}+0.124(L/2D)^{6}]D^{2.5} \qquad [1\text{-}12]$$

Rectangular Orifice

$$Q = 4.78\ H\ L\ D^{.5} \qquad [1\text{-}13]$$

Circular Orifice

$$Q = 3.754\ L^{2}\ D^{.5} \qquad [1\text{-}14]$$

where L, H, and D are width, height, and depth respectively of the breach. For a discussion of how the form and coefficients for these equations were derived the user should consult *A Quick Method For Computing Flows From Dam Breaks* (5).

III. Program Operation / Limitations

The flood routing routine is limited to 50 time steps and 100 segments (ten of which may be reservoir segments). For each reservoir, up to ten increasing stage-discharge-storage values may be entered using a reservoir rating curve supplied by the user. The dam breach routine may be utilized to derive the stage-discharge portion of a reservoir rating curve if so desired. For a given problem up to a maximum of five segments can be confluent into a single downstream segment. All headwater segments must be numbered consecutively from one and the other segments must be numbered such that upstream segments have smaller numbers than any segments downstream from them. Reservoir stages and beginning flows in each segment for a given problem are initialized to provide steady-state continuity with initial inflows into the headwater segments. The program then works its way downstream combining inflows at the top of each segment and routing flow to the bottom.

Initial input into the flood routing routine consists of:

1) Total Number of Segments,
2) Number of Headwater Segments,
3) Number of Reservoir Segments,
4) Number of Time Periods, and
5) Length of the Time Steps.

For each channel segment, the user is then prompted for the segment number, the Muskingam weighting value, and the Muskingam storage time constant. The segment numbers, number of rating curve points, and actual rating curve values must then be input for each reservoir segment. Inflow hydrographs into each headwater member can then be entered from the keyboard or from a previously saved data file. Each segment is then routed consecutively starting with segment number one in order of increasing segment number. After each segment is routed, the user is offered the option of generating a plot of the segment outflow hydrograph.

For the dam breach routine, the user must first select the type of breach to be analyzed and then select the weir or orifice shape. A graphic will then appear on the CRT or printer which illustrates the dimensions needed for the selected weir or orifice. For the weir breachs the width and depth of flow are required. For the circular orifice, the depth of flow to the center of the pipe and the diameter of the pipe are required. For the rectangular orifice, the height and width of the pipe and the depth of flow at its center are required. The number of flows which can be evaluated for a given run is unlimited.

IV. Example Problem

Flood Routing

The following example is taken from *Flood Routing on a Small Computer* (5) and consists of the following five segment network:

```
Input Hydrograph ->  \             /  <- Input Hydrograph
                      o           o
                       \         /
      Segment No. 1 ->  \       /
                         o     / <- Segment No. 2
                          \   /
         Segment No. 3 ->  \ /
                            \/
                            /\
                           /  \ <- Segment No. 4
                          /    \     (Reservoir)
                         /______\
                            |
          Segment No. 5 ->  |
                            o
```

Segments 1 and 2 are headwater segments with associated inflow hydrographs to be input by the user. In this example it is desired that the inflow hydrograph to segment 2 be transfered to the reservoir with no attenuation. In order to achieve this, segment 2 is given a Muskingam weighting factor of 0.5 and a storage time constant of 0.0 (note that the inflow and outflow hydrographs computed for segment 2 in the listing below are identical). The same procedure would be followed in the simple

case requiring the routing of a single inflow hydrograph through a single reservoir segment (i.e., this would be a two segment problem using a single channel segment with a weighting factor of 0.5 and a storage time constant of 0.0 influent into a single reservoir segment).

The reservoir site for this problem has been surveyed and an area-elevation relationship determined as follows:

Elevation (ft)	Area (ft^2)
0.0	0
.3	441,000
.5	435,600
1.0	435,600
1.5	435,600
2.0	435,600
2.5	435,600

The incremental volume of storage for each elevation increment was calculated from:

$$\Delta V = (A_1 + A_2)(z_2 - z_1)/2$$

where A_1 and A_2 are the water surface areas at elevations z_1 and z_2 and ΔV is the volume of storage between elevations z_1 and z_2. As can be inferred from the water surface areas, the reservoir has virtually vertical sides between the elevations .5 and 2.5 feet. The resulting stage-storage values are as follows:

Stage (ft)	Storage (ft^3)
0.0	0
.3	132,300
.5	217,800
1.0	435,600
1.5	653,400
2.0	872,100
2.5	1,089,000

The elevations listed above were then applied to the known geometry and elevation of the weir-shaped outlet structure to derive discharges using an appropriate weir equation which is similar to that used in the dam breach routines in the flood routing program. The resulting stage-discharge-storage values are as follows:

Stage (ft)	Discharge (cfs)	Storage (ft^3)
0.0	0.0	0
.3	1.0	132,300
.5	21.2	217,800
1.0	60.0	435,600
1.5	110.0	653,400
2.0	170.0	872,100
2.5	238.0	1,089,000

The remaining input is self evident in the example run listed below.

*BRN A403/FLOOD, R

This program routes a set of inflow hydrographs through a multiple channel and/or reservoir system using the Muskingam and Puls methods. The program also provides the option of analyzing expected flows due to a dam breach by either overtopping or piping. The following inputs are required for the routing routine:

* Input hydrographs for headwater segments
* Muskingam time constants for channels
* Muskingam weighting values for channels
* Stage/discharge/storage points for reservoirs
* Listing of confluent segments for each segment
* Number of time steps
* Length of each time step

Up to 100 channel and/or reservoir segments can be routed, up to 10 of which can be reservoirs. Each reservoir can have up to 10 arbitrary increasing stage/discharge/storage values. Up to five segments can be confluent into a single segment. Inflow hydrographs to headwater segments can be input from the keyboard or from a previously saved data file. Inflow hydrographs must define flows for each time step.

The dam breach analysis requires that water levels and dimensions of the breach be specified as per a diagram which appears on the screen. The dam breach option can also be used to generate stage/discharge/storage values for input to the routing routine.

SELECT THE PROCEDURE DESIRED:

    1 - FLOOD ROUTING
    2 - DAM BREACH ANALYSIS
    3 - END PROGRAM RUN

? 1

TOTAL NUMBER OF SEGMENTS? 5

NUMBER OF HEADWATER SEGMENTS? 2

```
NUMBER OF RESERVOIR SEGMENTS? 1

NUMBER OF TIME PERIODS? 15

LENGTH OF TIME STEP (HRS)? .5

ENTER SEGMENT NO., WEIGHTING VALUE, AND TIME CONSTANT FOR EACH CHANNEL:
(Three entries to a line, in above order, separated by commas)

? 1,.21,1.6
? 2,.5,0
? 3,.32,3.1
? 5,.27,1.9

ENTER SEGMENT NUMBER AND NUMBER OF STAGE-DISCHARGE-STORAGE
RATING CURVE POINTS TO BE INPUT FOR RESERVOIR NO.     1 :
(Two entries to a line, in above order, separated by commas)

? 4,7

ENTER STAGE(ft), DISCHARGE(cfs), AND STORAGE(cubic ft) FOR
EACH RATING CURVE POINT FOR RESERVOIR SEGMENT NO.     4 :
(Three entries to a line, in above order, separated by commas)

? 0,0,0
? .3,1,132300
? .5,21.2,217800
? 1,60,435600
? 1.5,110,653400
? 2,170,871200
? 2.5,238,1089000

DO YOU WISH TO ENTER INFLOW HYDROGRAPH FOR SEGMENT NO.     1
FROM THE KEYBOARD OR FROM A PREVIOUSLY GENERATED DATA
FILE ( 1 OR 2 ) ?

     1 - KEYBOARD
     2 - FILE

? 1

ENTER FLOW VALUE FOR EACH OF   15 TIME PERIODS:
(One entry to a line)

? 80
? 90
? 110
? 130
? 120
? 110
? 100
? 90
? 85
? 82
? 80
```

```
? 78
? 75
? 73
? 70
```

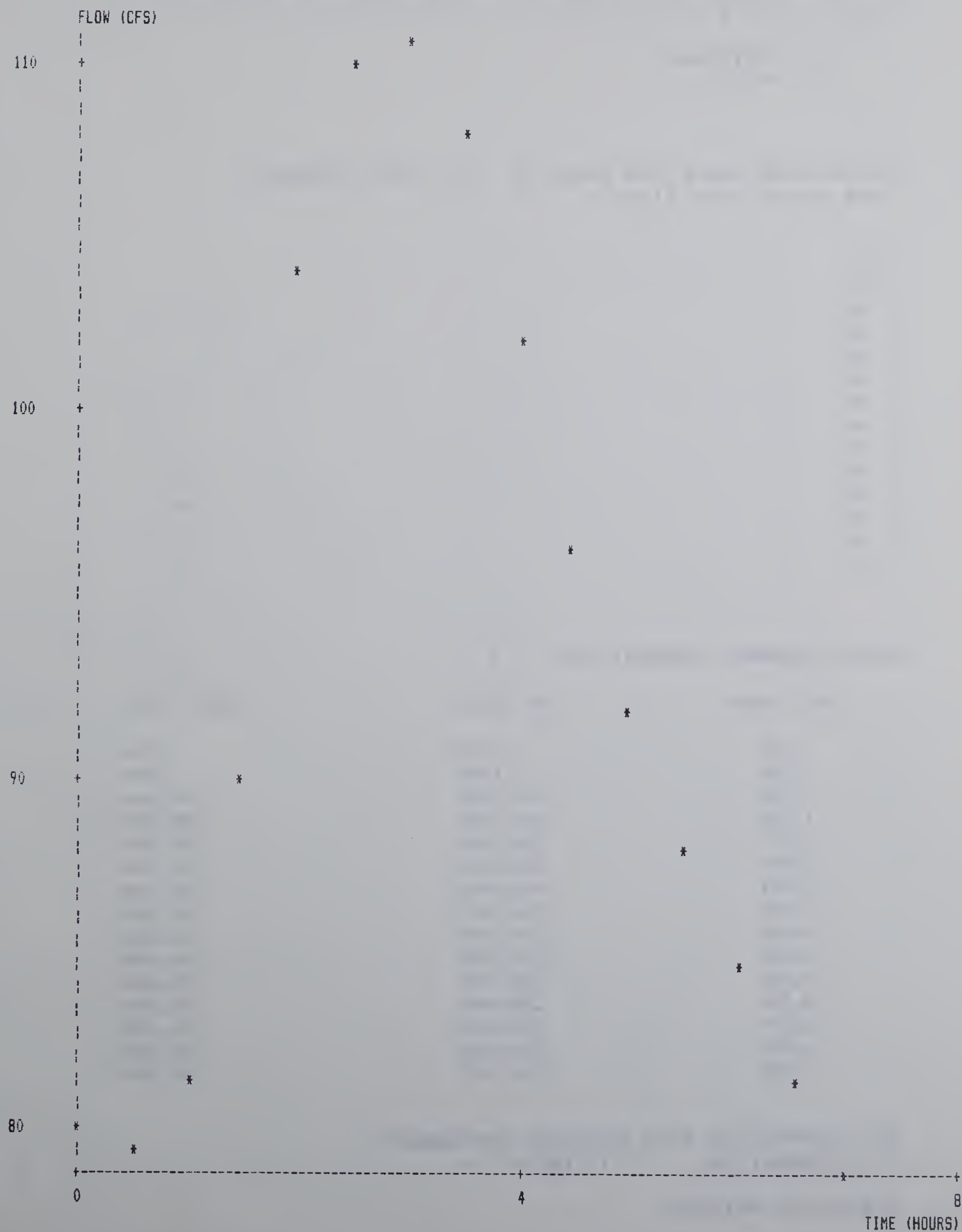
ROUTE CHANNEL SEGMENT NO.   1

TIME (HRS)	IN (CFS)	OUT (CFS)
.00	80.000	80.000
.50	90.000	79.432
1.00	110.000	81.786
1.50	130.000	89.968
2.00	120.000	103.756
2.50	110.000	109.689
3.00	100.000	110.360
3.50	90.000	107.506
4.00	85.000	102.009
4.50	82.000	96.562
5.00	80.000	91.867
5.50	78.000	88.061
6.00	75.000	84.909
6.50	73.000	81.750
7.00	70.000	79.031

DO YOU WISH TO PLOT OUTFLOW HYDROGRAPH
FOR SEGMENT NO.   1 (Y OR N)? Y

PLEASE BE PATIENT

OUTFLOW HYDROGRAPH FOR SEGMENT NO. 1



```
DO YOU WISH TO ENTER INFLOW HYDROGRAPH FOR SEGMENT NO.    2
FROM THE KEYBOARD OR FROM A PREVIOUSLY GENERATED DATA
FILE ( 1 OR 2 ) ?

     1 - KEYBOARD
     2 - FILE

? 1

ENTER FLOW VALUE FOR EACH OF   15 TIME PERIODS:
(One entry to a line)

? 0
? 0
? 40
? 45
? 50
? 50
? 45
? 40
? 36
? 30
? 30
? 35
? 40
? 35
? 30


ROUTE CHANNEL SEGMENT NO.    2

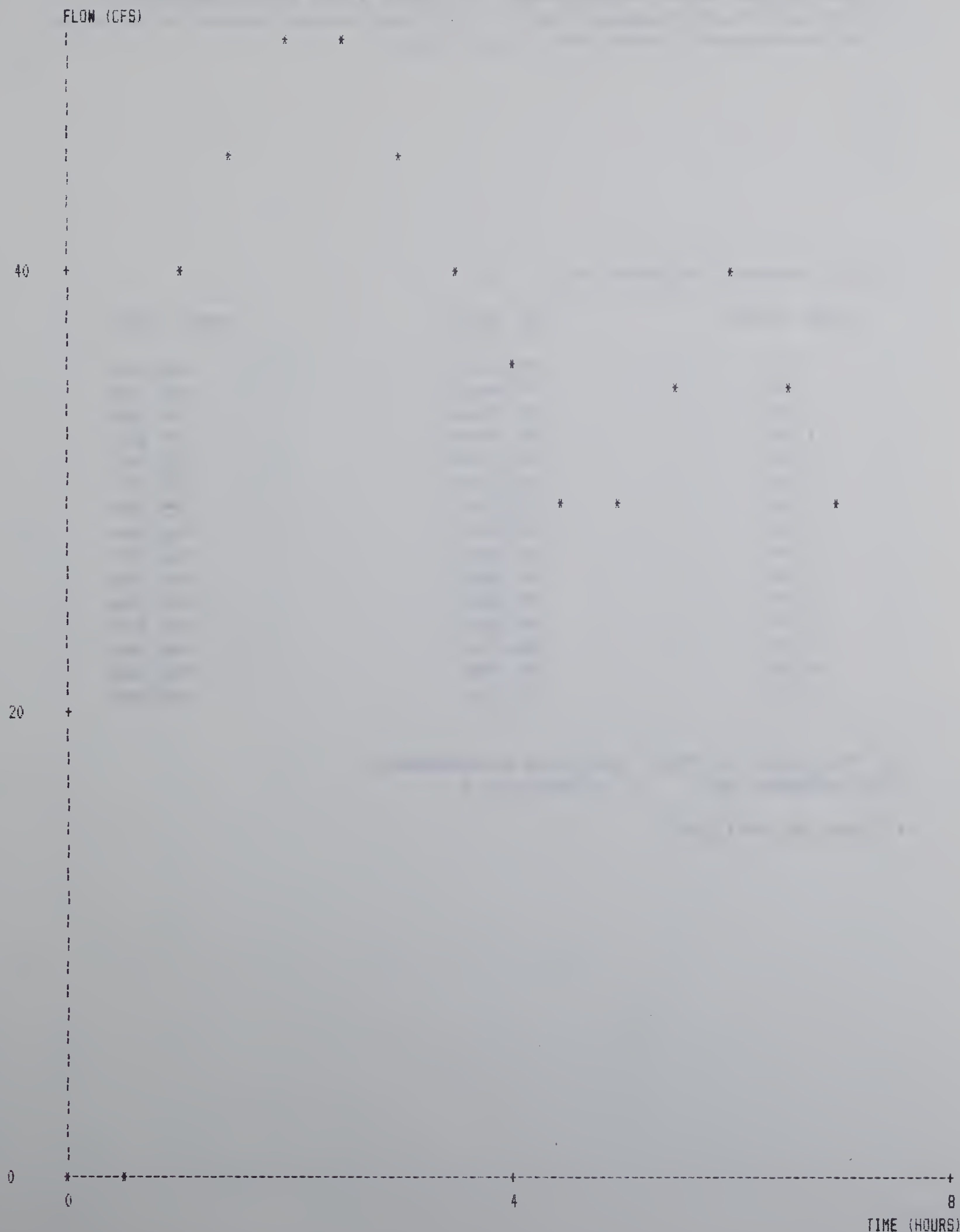
   TIME (HRS)           IN (CFS)             OUT (CFS)

       .00                 .000                  .000
       .50                 .000                  .000
      1.00               40.000                40.000
      1.50               45.000                45.000
      2.00               50.000                50.000
      2.50               50.000                50.000
      3.00               45.000                45.000
      3.50               40.000                40.000
      4.00               36.000                36.000
      4.50               30.000                30.000
      5.00               30.000                30.000
      5.50               35.000                35.000
      6.00               40.000                40.000
      6.50               35.000                35.000
      7.00               30.000                30.000

DO YOU WISH TO PLOT OUTFLOW HYDROGRAPH
FOR SEGMENT NO.    2 (Y OR N)? Y

PLEASE BE PATIENT
```

OUTFLOW HYDROGRAPH FOR SEGMENT NO. 2



```
ENTER INFLOW SEGMENTS TO SEGMENT NO.    3 :
(Five values must be entered, if less than five segments are
 confluent with Segment No.    3  then enter zeros to make up
 the difference. One entry to a line.)

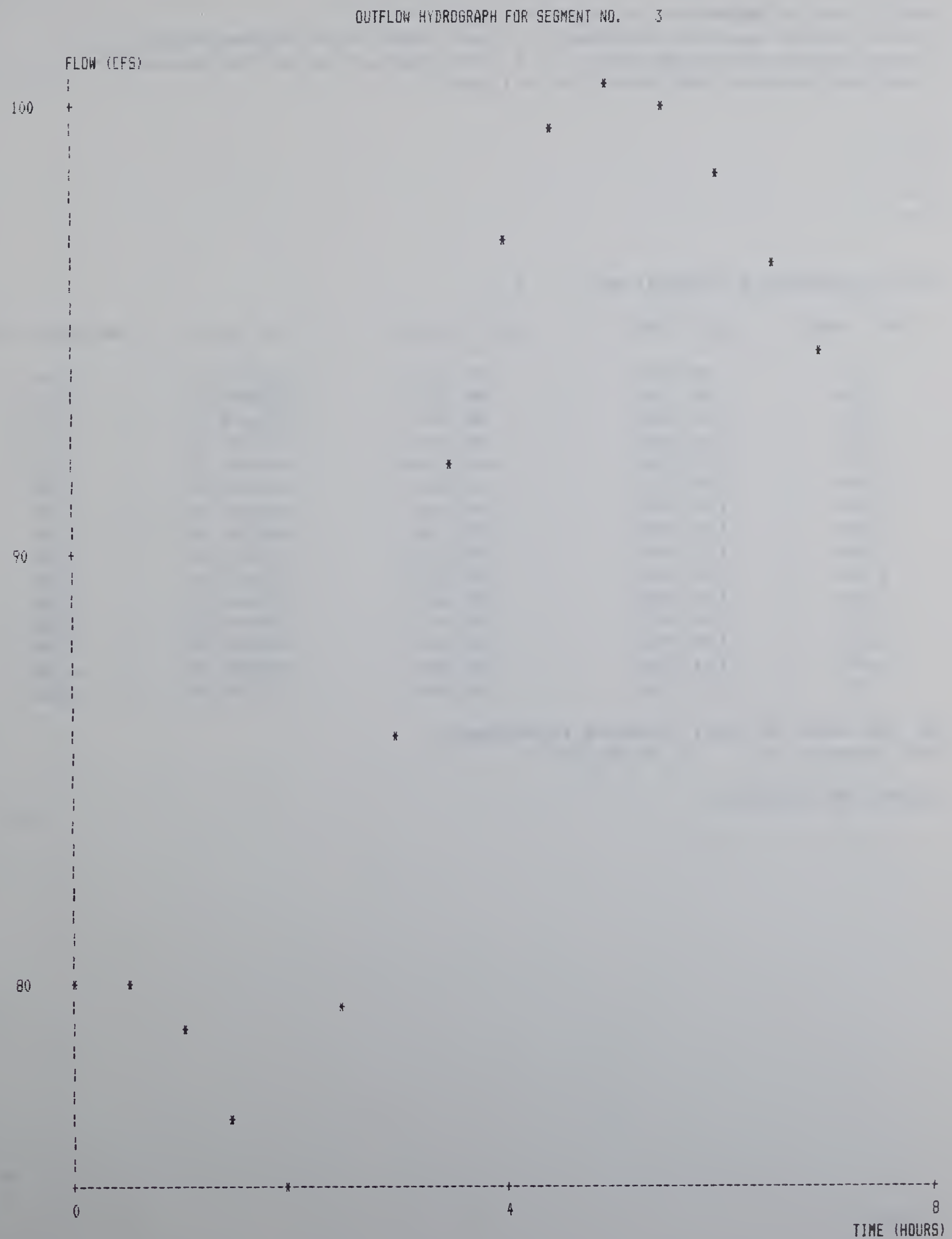
? 1
? 0
? 0
? 0
? 0
```

ROUTE CHANNEL SEGMENT NO.   3

TIME (HRS)	IN (CFS)	OUT (CFS)
.00	80.000	80.000
.50	79.432	80.179
1.00	81.786	79.280
1.50	89.968	77.237
2.00	103.756	75.597
2.50	109.689	79.701
3.00	110.360	85.849
3.50	107.506	91.944
4.00	102.009	96.974
4.50	96.562	99.756
5.00	91.867	100.556
5.50	88.061	99.911
6.00	84.909	98.390
6.50	81.750	96.526
7.00	79.031	94.248

DO YOU WISH TO PLOT OUTFLOW HYDROGRAPH
FOR SEGMENT NO.   3 (Y OR N)? Y

PLEASE BE PATIENT


OUTFLOW HYDROGRAPH FOR SEGMENT NO. 3
FLOW (CFS)
100
90
80
0
4
8
TIME (HOURS)

```
ENTER INFLOW SEGMENTS TO SEGMENT NO.    4 :
(Five values must be entered, if less than five segments are
 confluent with Segment No.    4  then enter zeros to make up
 the difference. One entry to a line.)

? 2
? 3
? 0
? 0
? 0

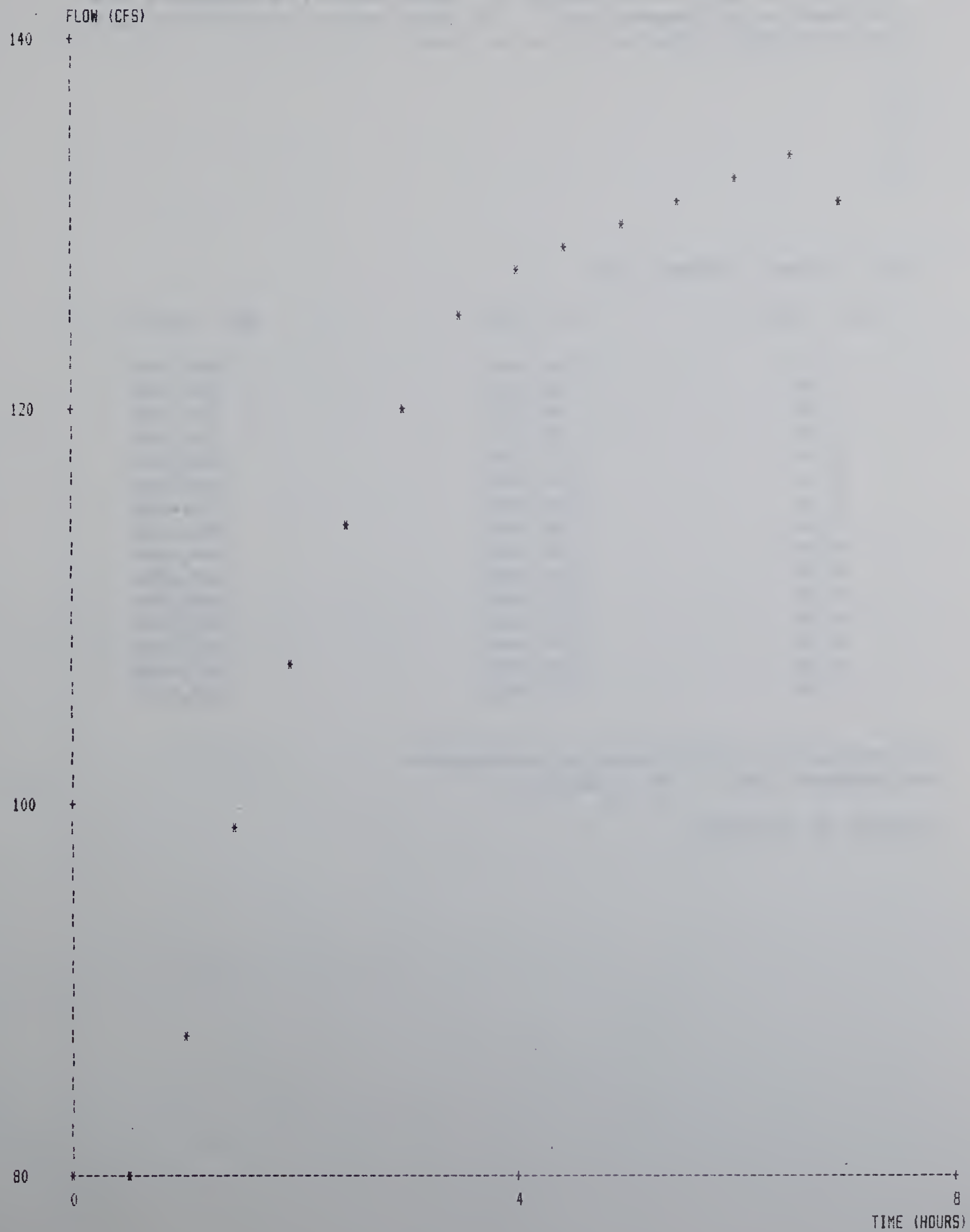

ROUTE RESERVOIR SEGMENT NO.    4
```

TIME (HRS)	IN (CFS)	OUT (CFS)	VOL (CF)	HEIGHT (FT)
.00	80.000	80.000	522720.0	1.20
.50	80.179	80.031	522853.3	1.20
1.00	119.280	86.777	552239.3	1.27
1.50	122.237	98.414	602932.1	1.38
2.00	125.597	107.148	640976.5	1.47
2.50	129.701	114.821	670973.0	1.54
3.00	130.849	120.942	693281.9	1.59
3.50	131.944	125.082	708374.4	1.63
4.00	132.974	128.004	719023.4	1.65
4.50	129.756	129.335	723875.3	1.66
5.00	130.556	129.660	725060.4	1.66
5.50	134.911	130.877	729497.2	1.67
6.00	138.390	133.164	737831.4	1.69
6.50	131.526	133.874	740421.5	1.70
7.00	124.248	131.503	731778.4	1.68

```
DO YOU WISH TO PLOT OUTFLOW HYDROGRAPH
FOR SEGMENT NO.    4 (Y OR N)? Y

PLEASE BE PATIENT
```

OUTFLOW HYDROGRAPH FOR SEGMENT NO.   4



```
ENTER INFLOW SEGMENTS TO SEGMENT NO.     5 :
(Five values must be entered, if less than five segments are
 confluent with Segment No.    5  then enter zeros to make up
 the difference. One entry to a line.)

? 4
? 0
? 0
? 0
? 0
```

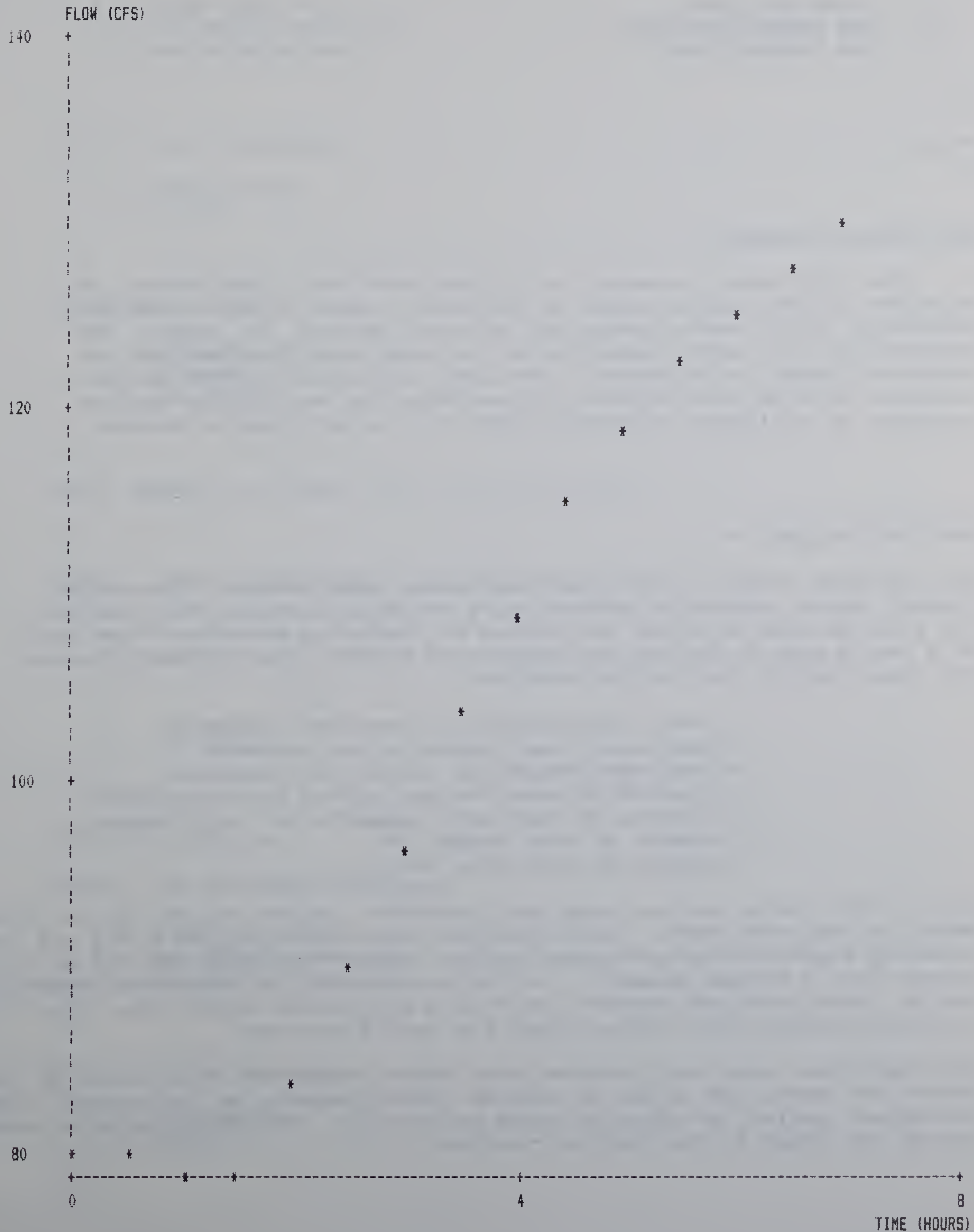
ROUTE CHANNEL SEGMENT NO. 5

TIME (HRS)	IN (CFS)	OUT (CFS)
.00	80.000	80.000
.50	80.031	79.995
1.00	86.777	78.922
1.50	98.414	79.452
2.00	107.148	83.840
2.50	114.821	89.726
3.00	120.942	96.408
3.50	125.082	103.236
4.00	128.004	109.439
4.50	129.335	114.896
5.00	129.660	119.254
5.50	130.877	122.237
6.00	133.164	124.508
6.50	133.874	127.038
7.00	131.503	129.507

DO YOU WISH TO PLOT OUTFLOW HYDROGRAPH
FOR SEGMENT NO.   5 (Y OR N)? Y

PLEASE BE PATIENT

OUTFLOW HYDROGRAPH FOR SEGMENT NO. 5



```
SELECT THE PROCEDURE DESIRED:

   1 - FLOOD ROUTING
   2 - DAM BREACH ANALYSIS
   3 - END PROGRAM RUN

? 3

ready
*
```

Dam_Breach_Analysis

The following example run illustrates the computation of expected flows from a number of different types of dam breaches including both overtopping and piping. As can be seen, the program is fully self prompting and no additional explanation of required input is necessary. The last evaluation in the series, using a circular pipe orifice, illustrates the ability to analyze a number of different possible flows for a given type of breach.

```
*BRN A403/FLOOD, R
```

This program routes a set of inflow hydrographs through a multiple channel and/or reservoir system using the Muskingam and Puls methods. The program also provides the option of analyzing expected flows due to a dam breach by either overtopping or piping. The following inputs are required for the routing routine:

* Input hydrographs for headwater segments
* Muskingam time constants for channels
* Muskingam weighting values for channels
* Stage/discharge/storage points for reservoirs
* Listing of confluent segments for each segment
* Number of time steps
* Length of each time step

Up to 100 channel and/or reservoir segments can be routed, up to 10 of which can be reservoirs. Each reservoir can have up to 10 arbitrary increasing stage/discharge/storage values. Up to five segments can be confluent into a single segment. Inflow hydrographs to headwater segments can be input from the keyboard or from a previously saved data file. Inflow hydrographs must define flows for each time step.

The dam breach analysis requires that water levels and dimensions of the breach be specified as per a diagram which appears on the screen. The dam breach option can also be used to generate stage/discharge/storage values for input to the routing routine.

```
SELECT THE PROCEDURE DESIRED:

   1 - FLOOD ROUTING
   2 - DAM BREACH ANALYSIS
   3 - END PROGRAM RUN

? 2

ENTER TYPE OF BREACH:

   1 - OVERTOPPING
   2 - PIPING

? 1

ENTER WEIR SHAPE:

   1 - RECTANGULAR
   2 - TRIANGULAR
   3 - PARABOLIC

? 1

ENTER NUMBER OF FLOWS (Q'S) TO BE COMPUTED:

? 1

ENTER L AND D DIMENSIONS (separate with comma):

   |- - - L - - -|
   *==============* - W A T E R  L E V E L
   *              * |
   *              * D
   *              * |
   * * * * * * * * -

? 35,10

EXPECTED FLOW (Q) =    3403.401

SELECT THE PROCEDURE DESIRED:

   1 - FLOOD ROUTING
   2 - DAM BREACH ANALYSIS
   3 - END PROGRAM RUN

? 2

ENTER TYPE OF BREACH:

   1 - OVERTOPPING
   2 - PIPING

? 1
```

```
ENTER WEIR SHAPE:

   1 - RECTANGULAR
   2 - TRIANGULAR
   3 - PARABOLIC

? 2

ENTER NUMBER OF FLOWS (Q'S) TO BE COMPUTED:

? 1

ENTER L AND D DIMENSIONS (separate with comma):

  |- - - - -  L  - - - - -|
  *=======================* - W A T E R  L E V E L
    *                   *   |
      *               *     |
        *           *       D
          *       *         |
            *   *           |
              *             -

? 35,10

EXPECTED FLOW (Q) =    1279.458

SELECT THE PROCEDURE DESIRED:

   1 - FLOOD ROUTING
   2 - DAM BREACH ANALYSIS
   3 - END PROGRAM RUN

? 2

ENTER TYPE OF BREACH:

   1 - OVERTOPPING
   2 - PIPING

? 1

ENTER WEIR SHAPE:

   1 - RECTANGULAR
   2 - TRIANGULAR
   3 - PARABOLIC

? 3

ENTER NUMBER OF FLOWS (Q'S) TO BE COMPUTED:

? 1
```

```
ENTER L AND D DIMENSIONS (separate with comma)

  ; - - - - - L - - - - - - ;
  *======================* - W A T E R   L E V E L
   *                    *  ;
    *                  *   D
      *              *     ;
             * *           -

? 35,10

EXPECTED FLOW (Q) =    1901.447

SELECT THE PROCEDURE DESIRED:

   1 - FLOOD ROUTING
   2 - DAM BREACH ANALYSIS
   3 - END PROGRAM RUN

? 2

ENTER TYPE OF BREACH:

   1 - OVERTOPPING
   2 - PIPING

? 2

ENTER ORIFICE SHAPE:

   1 - RECTANGULAR PIPE
   2 - CIRCULAR PIPE

? 1

ENTER THE NUMBER OF FLOWS (Q'S) TO BE COMPUTED:

? 1

ENTER L,H, AND D DIMENSIONS (separate with commas):

  ====================== - W A T E R   L E V E L
                         ;
                         ;
                         D
         - * * * * * * * ;
         ; *           * ;
         H *           * -
         ; *           *
         - * * * * * * *
           ;- -  L  - -;

? 8,5,10

EXPECTED FLOW (Q) =    604.6275
```

```
SELECT THE PROCEDURE DESIRED:

   1 - FLOOD ROUTING
   2 - DAM BREACH ANALYSIS
   3 - END PROGRAM RUN

? 2

ENTER TYPE OF BREACH:

   1 - OVERTOPPING
   2 - PIPING

? 2

ENTER ORIFICE SHAPE:

   1 - RECTANGULAR PIPE
   2 - CIRCULAR PIPE

? 2

ENTER NUMBER OF FLOWS (Q'S) TO BE COMPUTED:

? 2

ENTER L AND D DIMENSIONS (separate with comma):

  ========================== - W A T E R  L E V E L
                             :
                             :
              *              D
      *               *      :
                             :
    *                   *    -

      *               *
              *
    :- - - -  L  - - - -:

? 8,10

EXPECTED FLOW (Q) =     759.7562

? 10,10

EXPECTED FLOW (Q) =     1187.119
```

```
SELECT THE PROCEDURE DESIRED:

    1 - FLOOD ROUTING
    2 - DAM BREACH ANALYSIS
    3 - END PROGRAM RUN

? 3


ready
*
```

V. References

1. Chow, V.T. (ed.), 1964. Handbook of Applied Hydrology. McGraw-Hill, New York.

2. Heggen, R.J., 1983. Flood Routing on a Small Computer. Civil Engineering, March 1983.

3. Linsley, R.K., Jr., Kohler, M.A, and Paulhus, J.L.H., 1975. Hydrology for Engineers. McGraw-Hill Series in Water Resources and Environmental Engineering, New York.

4. McCarthy, G.T., 1938. The Unit Hydrograph and Flood Routing. Presented at Conf. North Atl. Div., U.S. Corps Eng., June 1938. See also Engineering Construction: Flood Control, pp. 147-156, The Engineer School, Ft. Belvoir, Va., 1940.

5. National Weather Service, 1979. A Quick Method For Computing Flows From Dam Breaks. National Weather Service, Washington, D.C.

2. BACKWATER CURVE AND VELOCITY PROGRAM

I. Introduction

A backwater curve is the water surface profile of flow in an open channel under gradually varied flow conditions. Gradually varied flow conditions occur when the cross section of flow along the channel varies gradually so that the resulting changes in velocity take place very slowly (1). This program enables the determination of the water surface profile and flow velocity for a fixed flow rate in a trapezoidal, rectangular, or triangular channel by the step method.

II. Program Theory

Changes in the cross section of flow along a channel can result from a change in the geometry of the channel through widening or narrowing or through the introduction of an obstruction such as a dam or another type of flow control structure. The resulting flow profiles can be classified on the basis of the slope of the channel and the relationships between the initial depth at which the profile is to start (Y_O), the normal flow depth (Y_N), and the critical flow depth (Y_C). The normal depth of flow is that obtained under uniform flow conditions for the channel geometry and flow rate given. For the given conditions, the depth of flow which occurs under the energy state which divides tranquil from rapid flow is termed critical depth. At this depth, the Froude number is equal to 1.

The bed slope may be mild, steep, or critical with corresponding M, S, or C profiles (Table 2.1) depending on the relationship of Y_N to Y_C. Each of these profile classifications can be further classified into three subgroups depending upon the relationships between Y_O, Y_N, and Y_C (Table 2.1). The profile classification determines whether the computation proceeds upstream or downstream, incrementing or decrementing from the initial depth until the normal depth is attained.

Table 2.1. - Water surface profiles and depth limits (2).

Type Slope[1]	Type Profile	Depth Relationships	Computational Procedure
Mild ($Y_N > Y_C$)	M1	$Y_O > Y_N$	Proceed upstream, decrementing depth, until normal depth is reached.
	M2	$Y_N > Y_O > Y_C$	Proceed upstream, incrementing depth, until normal depth is reached.
	M3	$Y_C > Y_O$	Proceed downstream, incrementing depth, until normal depth is reached.
Critical ($Y_N = Y_C$)	C1	$Y_O > Y_C$	Proceed upstream, decrementing depth, until normal depth is reached.
	C2	$Y_O = Y_C$	Profile is parallel to bed at $Y_O = Y_C = Y_N$, no procedure.
	C3	$Y_C > Y_O$	Proceed downstream, incrementing depth, until normal depth is reached.
Steep ($Y_C > Y_N$)	S1	$Y_O > Y_C$	Proceed upstream, decrementing depth, until normal depth is reached.
	S2	$Y_C > Y_O > Y_N$	Proceed downstream, decrementing depth, until normal depth is reached.
	S3	$Y_N > Y_O$	Proceed downstream, incrementing depth, until normal depth is reached.

[1] Y_O = Initial depth
Y_N = Normal depth
Y_C = Critical depth

The step method is the simplest procedure for computing backwater curves for a fixed rate of flow (2). The equation of motion for open channel flow can be written:

$$\frac{dE}{dx} = S \qquad [2\text{-}1]$$

where,

E = total energy of flow,
x = distance,
$S = S_o - S_f$ = energy grade line slope,
S_o = bed slope, and
S_f = friction slope.

Under the assumption of steady, uniform flow, the friction slope, S_f , is disregarded. In order to accurately predict a water surface profile, however, we must consider the energy loss due to flowing water. This energy loss is the friction slope term.

If flow rate, Q, channel roughness, n, bed slope, S, and channel geometry are known constants, and if the depth of water at two locations is known or specified, then the distance between the locations, ΔL, can be determined from (3):

$$L = \frac{Y_1 + \alpha\dfrac{V_1^2}{2g} - Y_2 + \alpha\dfrac{V_2^2}{2g}}{(S - S_o)}, \qquad [2\text{-}2]$$

where,

$i = 1, 2, 3, \ldots, n$,
Y_i = water depth at point i (ft),
ΔL = distance between points 1 and 2 (ft),
α = kinetic correction factor (often assumed to be 1),
g = gravitational constant (32.2 ft/sec^2),
V_i = water velocity at point i (ft/sec),

$$S_o = \frac{S_1 + S_2}{2}, \text{ and}$$

$$S_i = \left[\frac{Qn}{1.49\, A_i R_i^{2/3}}\right]^2,$$

where,

S_i = water surface slope at point i,
Q = flow (ft^3/sec),
A_i = cross-sectional area of flow at point i (ft^2),
n = Manning's n, and
R_i = hydraulic radius (ft).

Velocities are calculated from:

$$V = \frac{Q}{A}, \qquad [2-3]$$

where,

V = velocity (ft/sec),
A = cross-sectional area (ft^2), and
Q = flow rate (ft^3/sec).

The step procedure starts with a known depth of flow at the beginning of the channel segment (Y_o) and a given depth increment (I_o). The known channel geometry can then be used in Equations 2-2 and 2-3 to compute L, the length of the portion of the channel segment between Y_o and Y_o +- I_o. By repeating these computations for subsequent incremented or decremented depths, the entire backwater curve can be calculated up to the point where the normal depth is attained.

III. Program Operation / Limitations

After initial data input, the program will calculate the normal and critical depths. The user then inputs the initial depth and depth increment and the program selects and follows the appropriate computational procedure from Table 2.1. Positive distance values in the resulting output indicate steps downstream and negative distance values indicate steps upstream from the location of the initial depth.

In general, as I_o decreases, L decreases and the accuracy of the approximation of the energy slope increases (as does the accuracy of the backwater curve approximation). However, use of a smaller I_o increases computation iterations and the length of the tabular output.

The program is completely menu driven and input of necessary data as well as selection of optional output is prompted as the program is run. The user has the option of producing a plot of the backwater curve as part of the output. A complete listing of the variables used in the program as well as comments describing its operation can be found in the source code.

IV. Example Problem

This example deals with a portion of Donkey Creek which flows through a culvert underneath a road embankment downstream of a trailer park. The culvert tends to become clogged with trash and debris. If this results in raising the water level at the upstream face of the culvert to 2.2 feet, what will the resulting backwater surface profile look like for the mean annual flow ? This portion of the Donkey Creek channel has the following characteristics:

Channel side slope = 4.0 ft/ft
Channel bottom width = 30.0 ft
Channel bed slope = 0.0025 ft/ft
Manning's roughness coefficient = 0.035
Mean annual flow = 30 ft^3/sec

For the initial evaluation a depth increment of 0.1 ft will be used. If, after viewing the results, more accurate values are desired, they can be obtained by using a smaller increment.

```
*BRN A403/BACKH2O, R

This program uses the direct step method to determine a water surface
profile and flow velocities under gradually varied flow conditions for a
fixed rate of flow in a trapezoidal, rectangular, or triangular channel
by the standard step method.

The program also provides the capability to determine normal flow depth
or critical flow depth for a given channel cross section, Manning's n,
and flowrate. These depths can then be used as starting or ending points
for determining downstream or upstream water surface profiles and flow
velocities. This program will also generate a water surface profile plot
when requested by the user.

SELECT THE PROCEDURE DESIRED:

   1 - BACKWATER CURVE
   2 - END PROGRAM RUN

? 1

 *** INITIAL DATA ENTRY FOR NORMAL/CRITICAL DEPTH CALCULATION ***

ENTER FIXED RATE OF DISCHARGE, CFS:
? 30
ENTER CHANNEL BOTTOM WIDTH, FT (ZERO FOR TRIANGULAR CHANNEL):
? 30
ENTER CHANNEL SIDE SLOPE, RISE/RUN, FT/FT(ZERO FOR RECTANGULAR CHANNEL):
? 4
ENTER CHANNEL BED SLOPE, FT/FT:
? .0025
```

```
ENTER MANNING'S COEFFICIENT:
? .035

WAIT WHILE NORMAL DEPTH AND CRITICAL DEPTH ARE COMPUTED

     NORMAL DEPTH =   .63 FT
     CRITICAL DEPTH =  .31 FT

 *** ADDITIONAL DATA ENTRY FOR BACKWATER CURVE CALCULATION ***

ENTER INITIAL DEPTH, FT:
? 2.2
ENTER DEPTH INCREMENT, FT:
? .1

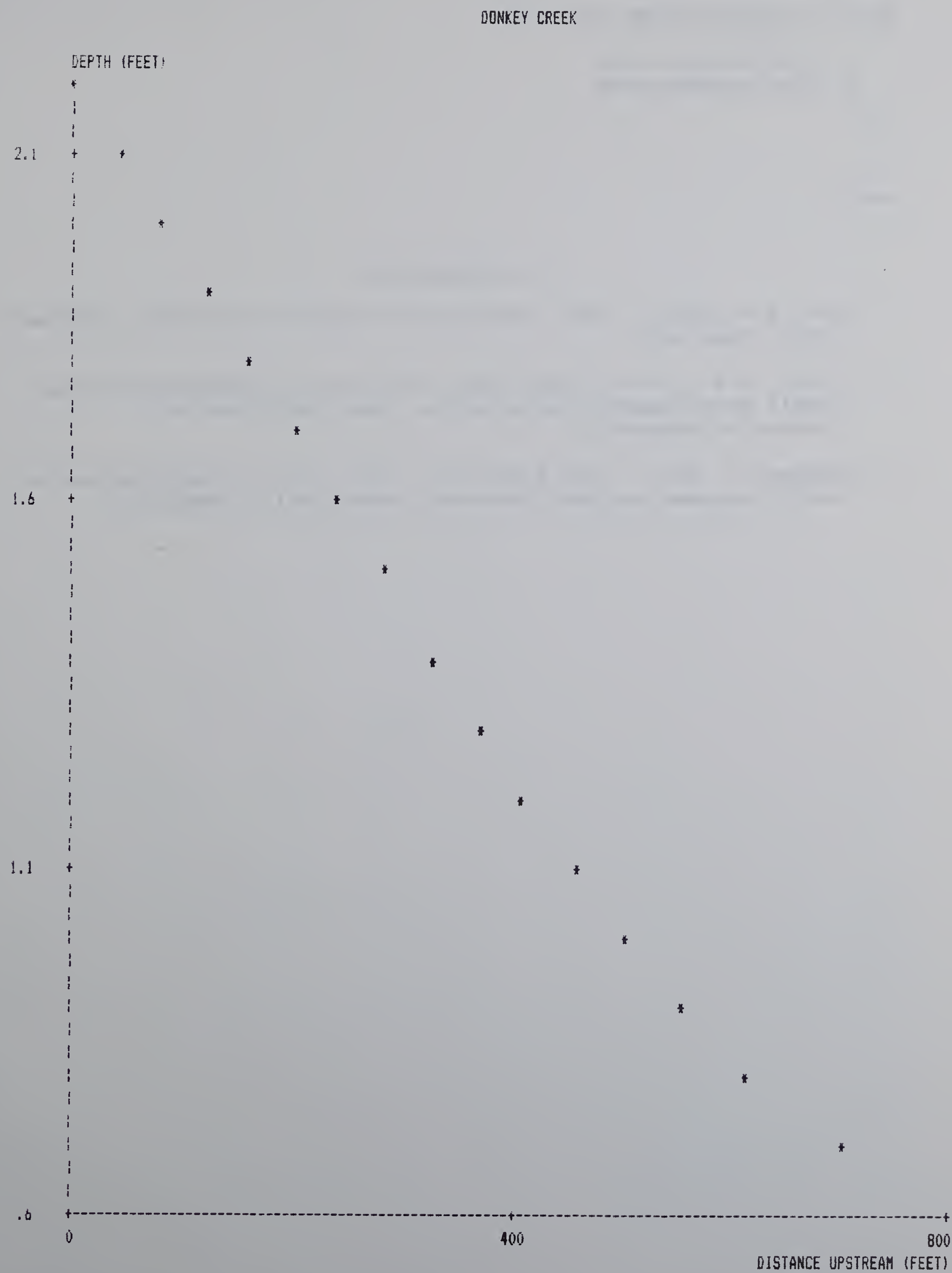
     *** WAIT WHILE BACKWATER CURVE IS CALCULATED ***

   DEPTH    CHG IN DIST     TOT DIST     VEL
================================================
     2.20        00.00         00.00        .35
     2.10       -40.47        -40.47        .37
     2.00       -40.56        -81.03        .39
     1.90       -40.67       -121.70        .42
     1.80       -40.82       -162.51        .45
     1.70       -41.00       -203.52        .48
     1.60       -41.25       -244.76        .52
     1.50       -41.57       -286.33        .56
     1.40       -42.02       -328.36        .60
     1.30       -42.65       -371.01        .66
     1.20       -43.57       -414.57        .72
     1.10       -44.97       -459.54        .79
     1.00       -47.24       -506.77        .88
      .90       -51.28       -558.05        .99
      .80       -59.69       -617.74       1.13
      .70       -84.09       -701.82       1.31
      .60      -420.22      -1122.04       1.54

DO YOU WISH TO PLOT BACKWATER CURVE (Y OR N)
? Y

ENTER TITLE FOR PLOT (30 CHARACTERS OR LESS)
? DONKEY CREEK

THIS WILL TAKE SOME TIME
```


DONKEY CREEK
DEPTH (FEET)
2.1
1.6
1.1
.6
0
400
800
DISTANCE UPSTREAM (FEET)

```
SELECT THE PROCEDURE DESIRED:

    1 - BACKWATER CURVE
    2 - END PROGRAM RUN

? 2


ready
*
```

V. References

1. Chow, V.T. (ed.), 1964. Handbook of Applied Hydrology. McGraw-Hill, New York.

2. Croley, T.E., 1977. Hydrologic and Hydraulic Computations on Small Programmable Calculators. Iowa Institute of Hydraulic Research.

3. Daugherty, R.L., and Franzini, J.B., 1977. Fluid Mechanics with Engineering Applications. McGraw-Hill, New York.

3. LOG PEARSON TYPE III ANALYSIS

I. Introduction

The determination of the probability of occurence of a flood of given magnitude is an important hydrologic problem. One method of making this determination is a statistical analysis of historical flow data. The log Pearson Type III curve has been selected as a common standard by federal agencies (3).

This program fits a series of events such as peak annual flows, to a log Pearson Type III distribution. Given an event of magnitude X, the program determines the probability of not exceeding X in any given year. The program also determines the recurrence interval (in years) of X.

II. Program Theory

The log Pearson Type III distribution is commonly used for predicting flood recurrence intervals. When this distribution is used it is assumed that the logarithms of the individual events can be fit to a type of curve originally derived by Karl Pearson (4). The distribution is actually a three-parameter Gamma distribution that uses the logarithms of the individual events as the random variate.

The Pearson Type III probability density function is:

F(y) = probability density function

$$= \frac{1}{\beta\Gamma(\alpha)} t^{\alpha - 1} e^{-t} \qquad [3\text{-}1]$$

where,

$$t = \frac{y - c}{\beta},$$

$$= \left[\frac{2}{\Psi}\right]^{2},$$

$$= \frac{s\,\Psi}{2},$$

$$c = \frac{\bar{y} - 2s}{\Psi}, \text{ and}$$

y = mean of y series,
s = standard deviation of y series,
ψ = skew coefficient of y series, and

$\Gamma(\alpha)$ = gamma function.

By integrating the probability density function for a given recurrence interval, Y, one can derive an equation of the form:

$$y = \bar{y} + sK \qquad [3\text{-}2]$$

where,

y_Y = event of recurrence interval Y, and

K = a function of skew and exceedence probability.

Table 3.1 enables one to easily determine K given probability (or recurrence interval) and skew.

Given a series (x series) of events x_1, x_2, x_3, ..., x_n, the program computes the series (y series) y_1, y_2, y_3, ..., y_n by taking the natural logarithm of each x. The normal statistical parameters y, s, and are calculated using the y values. The Pearson Type III parameters , , and c are computed from $\bar{y}$, s, and ψ. The probability of an event, y , can be calculated:

$$P(x < x_Y) = \left[\frac{a + m}{2\pi}\right]^{1/2} * \frac{(a + m - 1)!\alpha}{\alpha!} * \left[\frac{t}{\alpha + m}\right]^{\alpha}$$

$$* \left[\frac{1}{\alpha + m}\right]^{m} \exp\left[-t_Y + \alpha + m - \frac{1}{12(\alpha + m)}\right.$$

$$\left. + \frac{1}{360(\alpha + m)^3}\right] * \sum_{n=0}^{p} \frac{(t_Y)^n}{\alpha(\alpha + 1)\ldots(\alpha + n)} \qquad [3\text{-}3]$$

where,

$P(x < x_Y)$ = the probability that any randomly observed event x, will be less than or equal to the event x_Y that has a recurrence interval of Y years,

TABLE 3.1. - K values for use with Log Pearson Type III Distribution.
Probability, $P(y \leq y_\gamma)$
[Recurrence Interval (yrs) in Parenthesis]

Skew ψ	0.01 (1.01)	0.05 (1.05)	0.10 (1.11)	0.20 (1.25)	0.50 (2.0)	0.80 (5.0)	0.90 (10.0)	0.96 (25.0)	0.98 (50.0)	0.99 (100.0)	0.995 (200.0)
3.0	-.667	-.665	-.660	-.636	.396	.420	1.180	2.278	3.152	4.051	4.970
2.9	-.690	-.688	-.681	-.651	-.390	.440	1.195	2.277	3.134	4.013	4.905
2.8	-.714	-.711	-.702	-.666	-.384	.460	1.210	2.275	3.114	3.973	4.847
2.7	-.740	-.736	-.724	-.681	-.376	.479	1.224	2.272	3.093	3.932	4.783
2.6	-.769	-.762	-.747	-.696	-.368	.499	1.238	2.267	3.071	3.889	4.718
2.5	-.799	-.790	-.771	-.711	-.360	.518	1.250	2.262	3.048	3.845	4.652
2.4	-.832	-.819	-.795	-.725	-.351	.537	1.262	2.256	3.023	3.800	4.584
2.3	-.867	-.850	-.819	-.739	-.341	.555	1.274	2.248	2.997	3.753	4.515
2.2	-.905	-.882	-.844	-.752	-.330	.574	1.284	2.240	2.970	3.705	4.444
2.1	-.946	-.914	-.869	-.765	-.319	.592	1.294	2.230	2.942	3.656	4.372
2.0	-.990	-.949	-.895	-.777	-.307	.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-.984	-.920	-.788	-.294	.627	1.310	2.207	2.881	3.553	4.223
1.8	-1.087	-1.020	-.945	-.799	-.282	.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.140	-1.056	-.970	-.808	-.268	.660	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-1.093	-.994	-.817	-.254	.675	1.329	2.163	2.780	3.388	3.990
1.5	-1.256	-1.131	-1.018	-.825	-.240	.690	1.333	2.146	2.743	3.330	3.910
1.4	-1.318	-1.168	-1.041	-.832	-.225	.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-1.206	-1.064	-.838	-.210	.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-1.243	-1.086	-.844	-.195	.732	1.340	2.087	2.626	3.149	3.661
1.1	-1.518	-1.280	-1.107	-.848	-.180	.745	1.341	2.066	2.585	3.087	3.575
1.0	-1.588	-1.317	-1.128	-.852	-.164	.758	1.340	2.043	2.542	3.022	3.489
.9	-1.660	-1.353	-1.147	-.854	-.148	.769	1.339	2.018	2.498	2.957	3.401
.8	-1.733	-1.388	-1.166	-.856	-.132	.780	1.336	1.993	2.453	2.891	3.312
.7	-1.806	-1.423	-1.183	-.857	-.116	.790	1.333	1.967	2.407	2.824	3.223
.6	-1.880	-1.458	-1.200	-.857	-.099	.800	1.328	1.939	2.359	2.755	3.132
.5	-1.955	-1.491	-1.216	-.856	-.803	.808	1.323	1.910	2.311	2.686	3.041
.4	-2.029	-1.524	-1.231	-.855	-.066	.816	1.317	1.880	2.261	2.615	2.949
.3	-2.104	-1.555	-1.245	-.853	-.050	.824	1.309	1.849	2.211	2.544	2.856
.2	-2.178	-1.586	-1.258	-.850	-.033	.830	1.301	1.818	2.159	2.472	2.763
.1	-2.252	-1.616	-1.270	-.846	-.017	.836	1.292	1.785	2.107	2.400	2.670
.0	-2.236	-1.645	-1.282	-.842	.000	.842	1.282	1.751	2.054	2.326	2.576
-.1	-2.400	-1.673	-1.292	-.836	.017	.846	1.270	1.716	2.000	2.252	2.482
-.2	-2.472	-1.700	-1.301	-.830	.033	.850	1.258	1.680	1.945	2.178	2.388
-.3	-2.544	-1.726	-1.309	-.824	.050	.853	1.245	1.643	1.890	2.104	2.294
-.4	-2.615	-1.750	-1.317	-.816	.066	.855	1.231	1.606	1.834	2.029	2.201
-.5	-2.686	-1.774	-1.323	-.808	.083	.856	1.216	1.567	1.777	1.955	2.108
-.6	-2.755	-1.797	-1.328	-.800	.099	.857	1.200	1.528	1.720	1.880	2.016
-.7	-2.284	-1.819	-1.333	-.790	.116	.857	1.183	1.488	1.663	1.806	1.926
-.8	-2.891	-1.839	-1.336	-.780	.132	.856	1.166	1.448	1.606	1.733	1.837
-.9	-2.957	-1.858	-1.339	-.769	.148	.854	1.147	1.407	1.549	1.660	1.749
-1.0	-3.022	-1.877	-1.340	-.758	.164	.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	-1.894	-1.341	-.745	.180	.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	-1.910	-1.340	-.732	.195	.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	-1.925	-1.339	-.719	.210	.838	1.064	1.240	1.324	1.383	1.424
-1.4	-3.271	-1.938	-1.337	-.705	.225	.832	1.041	1.198	1.270	1.318	1.351

(Continued on next page.)

TABLE 3.1. - K values for use with Log Pearson Type III Distribution (cont.).
Probability, $P(y \leq y_\gamma)$
[Recurrence interval (yrs) in Parenthesis]

Skew Ψ	0.01 (1.01)	0.05 (1.05)	0.10 (1.11)	0.20 (1.25)	0.50 (2.0)	0.80 (5.0)	0.90 (10.0)	0.96 (25.0)	0.98 (50.0)	0.99 (100.0)	0.995 (200.0)
-1.5	-3.330	-1.951	-1.333	-.690	.240	.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.388	-1.962	-1.329	-.675	.254	.817	.994	1.116	1.166	1.197	1.216
-1.7	-3.444	-1.972	-1.324	-.660	.268	.808	.970	1.075	1.116	1.140	1.155
-1.8	-3.499	-1.981	-1.318	-.643	.282	.799	.945	1.035	1.069	1.087	1.097
-1.9	-3.553	-1.989	-1.310	-.627	.294	.788	.920	.996	1.023	1.037	1.044
-2.0	-3.605	-1.996	-1.302	-.609	.307	.777	.895	.959	.980	.990	.995
-2.1	-3.656	-2.001	-1.294	-.592	.319	.765	.869	.923	.939	.946	.949
-2.2	-3.705	-2.006	-1.284	-.574	.330	.752	.844	.888	.900	.905	.907
-2.3	-3.753	-2.009	-1.274	-.555	.341	.739	.819	.855	.864	.867	.869
-2.4	-3.800	-2.011	-1.262	-.537	.351	.725	.795	.823	.830	.832	.833
-2.5	-3.845	-2.012	-1.250	-.518	.360	.711	.771	.793	.798	.799	.800
-2.6	-3.889	-2.013	-1.238	-.499	.368	.696	.747	.764	.768	.769	.769
-2.7	-3.932	-2.012	-1.224	-.479	.376	.681	.724	.738	.740	.740	.741
-2.8	-3.973	-2.010	-1.210	-.460	.384	.666	.702	.712	.714	.714	.714
-2.9	-4.013	-2.007	-1.195	-.440	.390	.651	.681	.683	.689	.690	.690
-3.0	-4.051	-2.003	-1.180	-.420	.396	.636	.660	.666	.666	.667	.667

$$t = \frac{y_\gamma - c}{\beta} = \gamma\text{-quantile point for } t_\gamma ,$$

m = a positive integer, and
p = a positive integer.

The accuracy of the determination increases as p and m increase. To hold the number of computations to a reasonable level the values are chosen such that m is less than or equal to five and p is sufficiently large to ensure that the summation in the series expansion is accurate to over ten places.

This program is based on a program from *Hydrologic and Hydraulic Computations on Small Programmable Calculators* by Thomas E. Croley II (2). For a complete discussion of the mathematics involved, this reference is highly recommended. A brief description of the Pearson Type III probability density function can be found in the *Handbook of Mathematical Functions* (1).

III. Program Operation / Limitations

A maximum of 200 flows can be input for a single analysis. This amount was considered to be adequate for flow records for the vast majority of gaging stations (i.e., there are few stations in existance with periods of record longer than 200 years). This limit can be increased, however, by increasing the size of the arrays in the dimension statements for the appropriate variables.

The program allows entered flows to be saved to a disk file and then recalled and edited or added to during later runs. The program also allows entered flows to be reviewed and edited prior to the performance of the analysis. A plot of flows versus computed return periods can also be generated. The program is completely menu driven and input of necessary data as well as selection of optional output is prompted as the program is run. A complete listing of the variables used in the program as well as comments describing its operation can be found in the source code.

IV. Example Problem

This example deals with flow data from a USGS gaging station on Donkey Creek in the northern Powder River Basin, Wyoming. The objective is to evaluate the flows associated with a number of different return periods in order to determine the storage and spillway capacities for a flood control reservoir to be located in the Donkey Creek drainage. A total of 31 annual peak flows were available for the analysis:

YEAR	FLOW (cfs)	YEAR	FLOW (cfs)
1953	108.0	1970	567.0
1954	53.6	1971	122.0
1955	585.0	1972	151.0
1956	98.1	1973	244.0
1957	40.6	1974	400.0
1958	472.0	1975	245.0
1959	96.5	1976	114.0
1960	217.0	1977	659.0
1961	42.7	1978	132.0
1962	208.0	1979	44.0
1963	143.0	1980	72.5
1964	93.7	1981	135.0
1965	398.0	1982	635.0
1966	298.0	1983	508.0
1967	248.0		
1968	441.0		
1969	386.0		

*BRN A403/PEARSON, R

This program fits a series of flow events such as peak annual flows to a Log Pearson Type III distribution. This distribution is commonly used to predict flood recurrence intervals. Initial data input for a given gaging station is the number of measured peak flows and the amount of each flow in cubic feet per second (CFS). If flow data for a particular gaging station has been previously analyzed, and the

resulting output saved to a disk file, the disk file may be called up at the user's request in order to avoid re-inputting all of the flow amounts. Previously entered flows may also be edited and added to during later program runs. The program is limited to 200 flows per gaging station. The program begins by asking for the name of the file the output is to be written to. If an output file has been previously generated, the same file name may be used, or a different file name may be used to separate the results.

```
SELECT THE PROCEDURE DESIRED:

   1 - PEARSON
   2 - END PROGRAM RUN

? 1

INPUT NAME OF GAGING STATION (30 CHARACTERS OR LESS)
? DONKEY CREEK

DO YOU WISH TO INPUT FLOW DATA FROM THE KEYBOARD OR FROM A PREVIOUSLY
GENERATED DATA FILE (1 OR 2) ?

     1 - KEYBOARD
     2 - FILE

? 1

HOW MANY FLOWS IN FLOOD SERIES ? 31

ENTER EACH FLOW:

     1  ? 108
     2  ? 536
     3  ? 585
     4  ? 98.1
     5  ? 40.6
     6  ? 472
     7  ? 96.5
     8  ? 217
     9  ? 42.7
    10  ? 208
    11  ? 143
    12  ? 93.7
    13  ? 398
    14  ? 298
    15  ? 248
    16  ? 441
    17  ? 386
    18  ? 567
    19  ? 122
    20  ? 151
    21  ? 244
    22  ? 400
    23  ? 245
    24  ? 114
```

```
   25  ? 659
   26  ? 132
   27  ? 44
   28  ? 72.5
   29  ? 135
   30  ? 635
   31  ? 508

SELECT ONE FROM MENU BELOW:

     1 - EDIT FLOWS
     2 - COMPUTE RETURN PERIOD FOR A GIVEN FLOW
     3 - COMPUTE A FLOW FOR A GIVEN RETURN PERIOD
     4 - GENERATE A FLOOD FREQUENCY PLOT
     5 - EVALUATE NEW SET OF FLOWS
     6 - END PROGRAM RUN
? 1

      1    108.00        2    536.00        3    585.00        4     98.10
      5     40.60        6    472.00        7     96.50        8    217.00
      9     42.70       10    208.00       11    143.00       12     93.70
     13    398.00       14    298.00       15    248.00       16    441.00
     17    386.00       18    567.00       19    122.00       20    151.00
     21    244.00       22    400.00       23    245.00       24    114.00
     25    659.00       26    132.00       27     44.00       28     72.50
     29    135.00       30    635.00       31    508.00

     * NOTE NUMBER OF ANY FLOW AMOUNT WHICH IS INCORRECT !

DO YOU WISH TO CHANGE, ADD TO, OR LEAVE AS IS THE PREVIOUSLY
ENTERED FLOW AMOUNTS (1, 2 OR 3) ?

     1 - CHANGE
     2 - ADD TO
     3 - LEAVE AS IS

? 1

ENTER THE NUMBER OF THE FLOW YOU WISH TO CHANGE
? 2

PRESENT VALUE OF FLOW NO.    2  =   536  CFS
ENTER NEW VALUE
? 53.6
NEW VALUE OF FLOW NO.    2  =  53.6  CFS

DO YOU WISH TO CHANGE, ADD TO, OR LEAVE AS IS THE PREVIOUSLY
ENTERED FLOW AMOUNTS (1, 2 OR 3) ?

     1 - CHANGE
     2 - ADD TO
     3 - LEAVE AS IS

? 3
```

```
SELECT ONE FROM MENU BELOW:

     1 - EDIT FLOWS
     2 - COMPUTE RETURN PERIOD FOR A GIVEN FLOW
     3 - COMPUTE A FLOW FOR A GIVEN RETURN PERIOD
     4 - GENERATE A FLOOD FREQUENCY PLOT
     5 - EVALUATE NEW SET OF FLOWS
     6 - END PROGRAM RUN
? 2

ENTER DESIRED FLOW VALUE
? 1199
PROBABILITY THAT  1199  CFS WILL NOT BE EXCEEDED =    .9900085
RETURN PERIOD FOR  1199  CFS =    100.0853  YEARS

SELECT ONE FROM MENU BELOW:

     1 - EDIT FLOWS
     2 - COMPUTE RETURN PERIOD FOR A GIVEN FLOW
     3 - COMPUTE A FLOW FOR A GIVEN RETURN PERIOD
     4 - GENERATE A FLOOD FREQUENCY PLOT
     5 - EVALUATE NEW SET OF FLOWS
     6 - END PROGRAM RUN
? 2

ENTER DESIRED FLOW VALUE
? 1500
PROBABILITY THAT  1500  CFS WILL NOT BE EXCEEDED =    .9958601
RETURN PERIOD FOR  1500  CFS =    241.5543  YEARS

SELECT ONE FROM MENU BELOW:

     1 - EDIT FLOWS
     2 - COMPUTE RETURN PERIOD FOR A GIVEN FLOW
     3 - COMPUTE A FLOW FOR A GIVEN RETURN PERIOD
     4 - GENERATE A FLOOD FREQUENCY PLOT
     5 - EVALUATE NEW SET OF FLOWS
     6 - END PROGRAM RUN
? 3

OBTAIN K VALUE FROM TABLE 1 USING SKEW =   -.2012941 AND
DESIRED RETURN PERIOD (OR PROBABILITY).

ENTER K VALUE
? 1.680

FLOW =    784.2545  CFS
```

```
SELECT ONE FROM MENU BELOW:

     1 - EDIT FLOWS
     2 - COMPUTE RETURN PERIOD FOR A GIVEN FLOW
     3 - COMPUTE A FLOW FOR A GIVEN RETURN PERIOD
     4 - GENERATE A FLOOD FREQUENCY PLOT
     5 - EVALUATE NEW SET OF FLOWS
     6 - END PROGRAM RUN
? 3

OBTAIN K VALUE FROM TABLE 1 USING SKEW =   -.2012941 AND
DESIRED RETURN PERIOD (OR PROBABILITY).

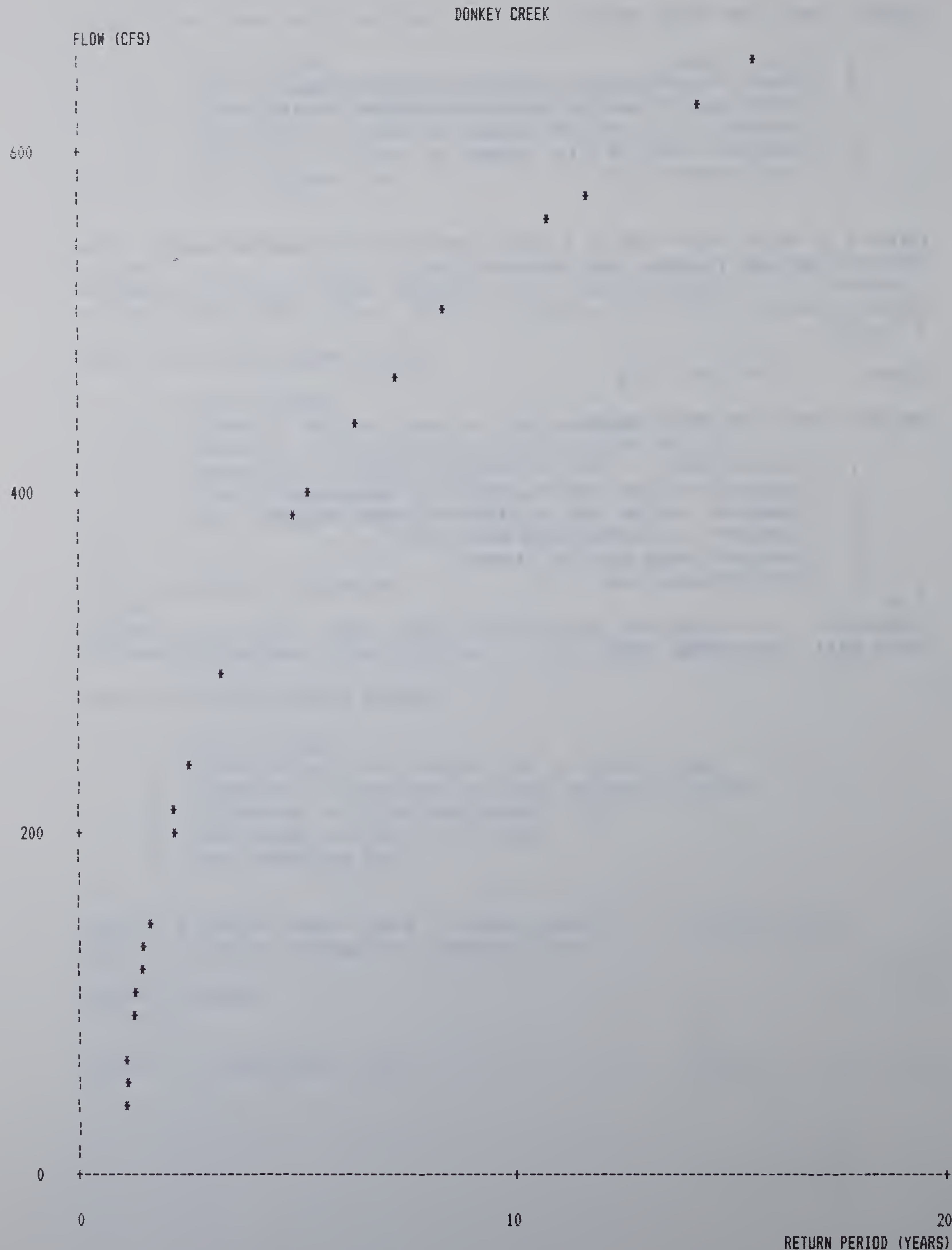
ENTER K VALUE
? 2.178

FLOW =    1199.296  CFS

SELECT ONE FROM MENU BELOW:

     1 - EDIT FLOWS
     2 - COMPUTE RETURN PERIOD FOR A GIVEN FLOW
     3 - COMPUTE A FLOW FOR A GIVEN RETURN PERIOD
     4 - GENERATE A FLOOD FREQUENCY PLOT
     5 - EVALUATE NEW SET OF FLOWS
     6 - END PROGRAM RUN
? 4

THIS WILL TAKE SOME TIME
```


DONKEY CREEK
FLOW (CFS)
600
400
200
0
0
10
20
RETURN PERIOD (YEARS)

```
SELECT ONE FROM MENU BELOW:

     1 - EDIT FLOWS
     2 - COMPUTE RETURN PERIOD FOR A GIVEN FLOW
     3 - COMPUTE A FLOW FOR A GIVEN RETURN PERIOD
     4 - GENERATE A FLOOD FREQUENCY PLOT
     5 - EVALUATE NEW SET OF FLOWS
     6 - END PROGRAM RUN
? 6

DO YOU WISH TO SAVE ENTERED FLOWS IN A DISK FILE ? (Y OR N)
? Y

ENTER NAME OF OUTPUT FILE (8 CHARACTERS OR LESS)
? DONCRK


ready
*
```

V. References

1. Abramowitz, M., and Stegun, I.E., 1970. Handbook of Mathematical Functions. Dover Publications, New York.

2. Croley, T.E., 1977. Hydrologic and Hydraulic Computations on Small Programmable Calculators. Iowa Institute of Hydraulic Research.

3. Hjelmfelt, A.T., and Cassidy, J.J., 1975. Hydrology for Engineers and Planners. Iowa State University, Ames, Iowa.

4. Pearson, K., 1930. Tables for Statisticians and Biometricians, 3rd Edition. Cambridge University Press, London.

5. Remenievas, G., 1967. "Statistical Methods of Flood Frequency Analysis", in Assessment of the Magnitude and Frequency of Flood Flows, Water Resources Series 30, United Nations World Meteorological Organization, New York, pp. 50-108.

4. UNIVERSAL SOIL LOSS EQUATION

I. Introduction

This program generally follows the procedure described in *Predicting Rainfall Erosion Losses - A Guide to Conservation Planning, USDA Agriculture Handbook No. 537*(6). The objective of this program is to calculate average erosion from an area. The equation on which the program is based was designed to predict long-term soil losses from sheet and rill erosion on given field slopes under specified land use and management. The program uses, as does the original equation, factors related to climate, soil, topography, and crop management. It is not intended here to provide a detailed discussion of the equation. Several good, readily obtainable references are mentioned in the following discussion and included in the list of references.

II. Program Theory

The Universal Soil Loss Equation (USLE) is an empirically developed formula used to estimate soil loss on agricultural lands. Although it was developed for eastern crop lands, it is potentially a useful tool for predicting erosion under a variety of land uses.

The USLE only accounts for sheet and rill erosion. No erosion from gullying is considered. In the western U.S. gully erosion is often the principal source of sediment. Thus, the USLE may not represent a comprehensive total of all erosion from an area.

The USLE only considers average erosion, not the sediment delivery ration to a stream channel. When applying the USLE to estimate sediment impacts on surface water quality, the total erosion computed by the USLE must be adjusted with the appropriate sediment delivery ratio.

The USLE is:

$$USLE = (R)\ (K)\ (LS)\ (C)\ (P) \qquad [4-1]$$

where,

R = the rainfall factor, is the number of erosion index units in a normal year's rain; the erosion index is a measure of the erosive force of specific rainfall,

K = the soil erodibility factor, is the erosion rate per unit of erosion index for a specific soil and a standard set of conditions,

LS = the slope length and topographic factor,

C = crop management factor is the ratio of soil loss from a field with a specified crop management to a fallow soil, and

P = erosion control practice factor, is the ratio of soil loss, under specified erosion control practices, to a soil plowed in straight furrows up and down the slope.

When working with the USLE, special attention must be paid to the R factor which is a measurement of the kinetic energy of expected rainstorms for a specific geographical area. The R value for a given locality in the Western U.S. can be found on figure 1 of *Preliminary Guidance for Estimating Erosion on Areas Disturbed by Surface Mining in the Interior Western United States* (2).

The R factor for the western U.S. can also be estimated from the 2-year, 6-hour rainfall by using the equation (2):

$$R = 27.38\ P^{2.17} \qquad [4\text{-}2]$$

where,

R = rainfall factor in USLE, and
P = inches of rainfall in the 2-year, 6-hour storm.

The 2-year, 6-hour storm can be found in the appropriate volume (one volume for each state) of *NOAA Atlas 2, Precipitation Frequency Atlas of the Western United States* (3).

The R factor does not consider erosion caused by snowmelt runoff. Limited data suggests that R for the period of snowmelt can be estimated as 1.5 times the local December-March precipitation, in inches of water. This number is then added to the R computed for rainfall to give the total yearly R values.

R factors can also be estimated for part of the year. The monthly distribution of R is known for several locations in the western U.S. Table 7 of *Predicting Rainfall Erosion Losses* (6) shows the monthly distribution of R at selected western locations.

Some soils erode more readily than others and this characteristic is accounted for in the USLE by the K factor. Appendix A of *Preliminary Guidance for Estimating Erosion on Areas Disturbed by Surface Mining Activities in the Interior Western United States* (2) gives K factors for all established soil series in the western U.S. The K factor can also be estimated with the following equation (6):

$$K = (2.1 \times 10^{-6})(M^{1.14})(12-a) + .0325(b-2) + .025(c-3) \qquad [4\text{-}3]$$

where,

M = particle size parameter, defined as [(% silt + very fine sand) x (100 - % clay)].
a = % organic matter,
b = soil structure code, and
c = permeability class.

When b is:	Structure is:
1	very fine granular
2	fine granular
3	medium or coarse granular
4	blocky, platy, or massive

When c is:	Permeability is:
1	rapid
2	moderate to rapid
3	moderate
4	slow to moderate
5	slow
6	very slow

This equation is only accurate when:

1) % silt plus very fine sand < 70%, and
2) % organic matter < 4%.

The length and steepness of slopes in an area are important determinants of the rate of erosion. The LS factor in the USLE accounts for the topographic influence of relief on the rate of erosion. For uniform slopes, LS is determined from the following equation (6):

$$LS = (\lambda/72.6)^m\ ((65.41 * \sin\theta^2 + (4.56 * \sin\theta) + .065) \qquad [4\text{-}4]$$

where,

LS = slope length and gradient factor,
λ = length of slope (ft),
θ = angle of slope - rise/run, and
m = 0.5 if slope > or = 5.0%,
0.4 if slope > or = 3.5% and < 5.0%,
0.3 if slope > or = 1.0% and < 3.5%, or
0.2 if slope < 1.0%.

This equation is solved by assuming:

$$\theta = \tan\theta = \sin\theta .$$

This is true for small θ. At a slope of as much as 20 percent, the error in the calculated LS factor is about three percent.

For irregular slopes (where θ changes), the LS factor can be computed by first dividing the slope into equal length segments of constant slope. The LS factor for each segment is then computed. The following equation is used to adjust the LS factor of each segment:

$$x = \frac{I^{m+1} - (I-1)^{m+1}}{N^{m+1}} \qquad [4\text{-}5]$$

where,

x = segment adjustment factor,
I = segment sequence number (segment number 1 is always at the top of the slope),
N = number of segments, and
m = 0.5 if slope > or = 5.0%,
0.4 if slope > or = 3.5% and < 5.0%,
0.3 if slope > or = 1.0% and < 3.5%, or
0.2 if slope < 1.0%.

The adjusted segment LS factors are then summed to give the total LS factor for the slope.

The C factor is the ratio of soil loss cropped under specified conditions to the corresponding loss from clean-tilled fallow soil. Numerous references are available to help estimate the cropping factor. See Tables 2, 3, 4, and 5 in *Preliminary Guidance for Estimating Erosion on Areas Disturbed by Surface Mining Activities in the Interior Western United States* (2), Tables 2, 3, and 4 in *Procedure for Computing Sheet and Rill Erosion on Project Areas, USDA-SCS Technical Release No. 51* (1), and Tables 5, 8, 9, 10, 11, and 12 in *Predicting Rainfall Erosion Losses - A Guide to Conservation Planning*, (6). Table 10 from the later is reproduced below as Table 4-1 and is recommended as a source for C values.

TABLE 4-1.- Factor C for permanent pasture, range, and idle land (6)[1].

VEGETATIVE CANOPY		COVER THAT CONTACTS THE SOIL SURFACE						
Type and Height[2]	Percent Cover[3]	Type[4]	Percent Ground Cover 0	20	40	60	80	95+
No appreciable canopy.		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.011
Tall weeds or short brush with average drop fall height of 20 in.	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes, with average drop fall height of 6.5 ft.	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, but no appreciable low brush. Average drop fall height of 13 ft.	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

[1] The listed C values assume that the vegetation and mulch are randomly distributed over the entire area.

[2] Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.

[3] Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).

[4] G: cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 in. deep.

W: cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues or both.

The P Factor measures the influence of various erosion control practices such as contour plowing and cultivated strips along the contour, on soil loss. For areas without these factors, (bare soil, rangeland, reclaimed land) set P = 1.0. Table 6 of *Preliminary Guidance for Estimating Erosion on Areas Disturbed by Surface Mining Activities in the Interior Western United States*, (2) shows appropriate P values.

Terracing does not impact the P factor in the USLE. Terracing is accounted for in the LS factor by a reduction in slope length (L is the length of a single terrace).

III. Program Operation / Limitations

The USLE is an erosion model designed to compute longtime average soil losses from sheet and rill erosion under specified conditions. It is also useful for construction sites and other non-agricultural conditions, but it does not predict deposition and does not compute sediment yields from gully, streambank, and streambed erosion (6). The accuracy of the estimates resulting from the use of the USLE are dependent upon the accuracy of the estimates made for the various factors contained in the model. An excellent starting point for a discussion of significant limitations in the available data for each of the factors is USDA Agriculture Handbook 537 entitled, *Predicting Rainfall Erosion Losses - A Guide to Conservation Planning*(6).

The program allows soil losses to be computed for a single basin or to be cummulated for a series of basins. There is no practical limit to the number of basins which can assessed in a given run. The program also allows a sediment delivery ratio to be applied to the calculated soil losses in order to estimate the amount of sediment actually being delivered to the stream channel. The sediment delivery ratio applied is, of course, dependent upon the user's knowledge of the basin or basins being analyzed.

The program is totally menu driven and input of the necessary data is throughly prompted as the program is run. Care should be taken that the desired values have been typed at the keyboard for each factor before the value is entered into the program by hitting the return key. This will save having to re-enter all values for a given run and will maintain the accuracy of the cummulative soil loss result. A complete listing of the variables used in the program as well as comments describing its operation can be found in the source code.

IV. Example Problem

This example uses information from a Mine Permit Application for the Rawhide coal mine in Wyoming's Powder River Basin. The objective is to estimate the average annual erosion rate from a disturbed area near the mine in order to help in determining the required storage capacity for the Rawhide Mine Main Reservoir. The following information was supplied in the permit application:

R = 50.0
K = 0.31
Lo = 1750.0 ft
So = 7.5%
C = 0.45
P = 1.0
Disturbed Area = 5.01 acres

```
*BRN A403/USLE, R

This program generally follows the  procedure described  in 'Predicting
Rainfall  Erosion  Losses  -  A  Guide to Conservation Planning', USDA,
Agriculture Handbook No. 537, 1978.

The program  uses the  Universal Soil Loss Equation  (USLE) to estimate
soil loss from a given  acreage of  land.  The USLE  is an  empirically
developed formula intended to estimate soil loss on agricultural lands.
The USLE only  accounts for  sheet  and rill  erosion.  No erosion from
gullying is considered. In the western U.S., gully erosion is often the
principal source of sediment. Thus, the USLE may not  represent a comp-
rehensive total of erosion from an area in the western U.S. The USLE
only considers average  erosion, not the sediment delivery  ratio  to a
stream channel. When applying the USLE to estimate sediment  impacts on
surface water quality, the total erosion computed by the  USLE  must be
adjusted with the appropriate sediment delivery ratio. This pro-
gram allows the option of a sediment delivery  ratio to be  input after
the amount of  average soil  erosion  has  been calculated. To continue
the program run, select '1' from the following menu:

  1 - COMPUTE A SOIL LOSS ESTIMATE FOR A NEW BASIN OR GROUP OF BASINS
  2 - COMPUTE A SOIL LOSS ESTIMATE TO BE ADDED TO PREVIOUS ESTIMATE
  3 - COMPUTE SEDIMENT YIELD
  4 - END PROGRAM RUN

? 1

TITLE FOR THE OUTPUT FROM THIS RUN? RAWHIDE MAIN RESERVOIR
```

The USLE accounts for soil erosion through the application of a number of factors. The form of the equation is:

USLE = (R) (K) (LS) (C) (P)

R = Rainfall Factor
K = Soil Erodibility Factor
LS = Slope Length and Topographic Factor
C = Crop Management Factor
P = Erosion Control Practice Factor

R, the rainfall factor, is the number of erosion index units in a normal year's rain. The erosion index is a measure of the erosive force of specific rainfall. The R factor measures the kinetic energy of expected rainstorms for a specific geographical area. The R factor for the western U.S. can be estimated from the 2-year, 6-hour rainfall. Select one from the following list:

1 - ENTER R DIRECTLY
2 - COMPUTE R FROM 2-YEAR, 6-HOUR STORM

? 1

R? 50

K, the soil erodibility factor, is the erosion rate per unit of erosion index for a specific soil and a standard set of conditions. The K factor can be estimated from a particle size parameter, % organic matter, a soil structure code, and a permeability class. This estimation is only accurate when less than 70% of the soil is made up of silt plus very fine sand and less than 4% is made up of organic matter. Select one from the following list:

1 - ENTER K DIRECTLY
2 - ESTIMATE K FROM SOIL CHARACTERISTICS

? 1

K? .31

LS, the slope length and topographic factor, accounts for the influence of topographic relief on the rate of erosion. For uniform slopes LS is determined from the length of slope, the angle of slope, and the category of slope. For irregular slopes (where the angle of slope changes), LS can be computed by first dividing the slope into equal length segments of constant slope and providing the same set of parameters for each segment. Slope length is defined as the length from the point of origin of overland flow to a point of sediment deposition or a confined channel, whichever is shorter. Therefore, slope length may not always be

the distance from ridge line to channel. Select one from the following list:

1 - UNIFORM SLOPE
2 - IRREGULAR SLOPE

? 1

LENGTH OF SLOPE (FT)? 1750

ANGLE OF SLOPE (RISE/RUN X 100)? 7.5

C, the crop management factor, is the ratio of soil loss from a field with a specified crop management to soil loss from a field with fallow soil. A recommended source for C values is Table 10 of Agriculture Handbook No. 537. This table is reproduced in the user guide for this program.

C? .45

P, the erosion control practice factor, is the ratio of soil loss under specified erosion control practices, to soil loss from soil plowed in straight furrows up and down the slope. For areas which have no erosion control practices or for areas which are not plowed (e.g., bare soil, rangeland, reclaimed land), set P = 1.0.

P? 1.0

To determine total tons of sediment production for the entirety of the basin or sub-basin being assessed, input the area of the basin or sub-basin in acres.

BASIN ACRES? 5.01

RAWHIDE MAIN RESERVOIR

```
RAINFALL FACTOR =                              50.0000
ERODIBILITY FACTOR =                             .3100
SLOPE LENGTH AND TOPOGRAPHIC FACTOR =           3.8031
CROP MANAGEMENT FACTOR =                         .4500
EROSION CONTROL PRACTICE FACTOR =               1.0000
ACRES IN BASIN OR SUB-BASIN =                   5.0100

RATE OF SOIL LOSS =      26.53 TONS/ACRE/YEAR
TOTAL SOIL LOSS =       132.90 TONS/YEAR
CUMMULATIVE SOIL LOSS FOR ALL BASINS ANALYZED =      132.90 TONS/YEAR
```

```
  1 - COMPUTE A SOIL LOSS ESTIMATE FOR A NEW BASIN OR GROUP OF BASINS
  2 - COMPUTE A SOIL LOSS ESTIMATE TO BE ADDED TO PREVIOUS ESTIMATE
  3 - COMPUTE SEDIMENT YIELD
  4 - END PROGRAM RUN

? 4

ready
*
```

The estimated rate of erosion loss for this problem is 132.90 tons/year. If we assume a unit weight for the material of 100 lbs/ft^3, we can compute the following:

$$132.90 \text{ tons} \times 2000 \text{ lbs/ton} = 265{,}800 \text{ lbs}$$

$$265{,}800 \times 1 \text{ ft}^3/100 \text{ lbs} = 2658 \text{ ft}^3$$

$$2658 \text{ ft}^3 \times 1 \text{ acre ft}/43560 \text{ ft}^3 = .061 \text{ acre ft}$$

The Rawhide Mine Permit Application also gives a value of 0.061 acre ft.

V. References

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5. GREEN AND AMPT INFILTRATION ANALYSIS

I. Introduction

The Green and Ampt (10) model is widely used for modeling infiltration (4). It is a relatively simple, physically based, two-parameter infiltration equation which can be derived from a direct application of Darcy's Law. This program implements a single-layer, homogeneous soil version which can accept a rainfall hyetograph as input.

II. Program Theory

The Green and Ampt model assumes that there is a well defined horizontal boundry or *wetting front* which divides the upper and lower portions of the soil column under consideration. In the upper portion the soil is completely saturated from the rainfall on the surface. Below the wetting front the original characteristic water content is maintained and does not influence the rate of saturation. The resulting process is termed *piston flow* and the hydraulic parameters can be derived by substituting the gradient into the Darcy equation for saturated flow.

The following discussion is taken from Eggert, et al. (8) upon which the program described herein is based.

A Green-Ampt type equation may be written as:

$$\frac{F}{\sigma} - \ln(1 + \frac{F}{\sigma}) = \frac{Kt}{\sigma}, \qquad [5\text{-}1]$$

in which F is the infiltrated volume, K is the hydraulic conductivity of the soil in the wetted zone, t is the time, and is the potential head parameter defined as:

$$\sigma = (\theta_w - \theta_i)\,\Psi_{ave}, \qquad [5\text{-}2]$$

in θ_w is the moisture content of the soil after wetting, θ_i is the antecedent moisture content, and Ψ_{ave} is the average suction head across the wetting front.

If at any time, t, the infiltrated volume is F(t), then at some later time t + Δt:

$$F(t + \Delta t) = F(t) + \Delta F \qquad [5\text{-}3]$$

in which ΔF is the change in infiltrated volume which occurred during the time increment, Δt. An expression for ΔF is obtained from Equation 5-3:

$$\Delta F = F(t + \Delta t) - F(t) \qquad [5\text{-}4]$$

Li et al. (8) developed the following method of solving for the infiltration rate. Their derivation yields:

$$\frac{\Delta F}{\sigma} - \ln\left[\frac{\sigma + F(t) + \Delta F}{\sigma + F(t)}\right] = \frac{K}{\sigma}\,\Delta t \qquad [5\text{-}5]$$

Equation 5-5 is implicit with respect to ΔF. However, the equation is simplified by expanding the logarithmic term in a power series (8):

$$\ln\left(1 + \frac{\Delta F}{\sigma + F}\right) = \ln 1 + \frac{\dfrac{2\,\Delta F}{\sigma + F}}{2 + \dfrac{\Delta F}{\sigma + F}} + \ldots \qquad [5\text{-}6]$$

Truncating Equation 5-6 after the second term and substituting into Equation 5-5, one obtains:

$$\frac{\Delta F}{\sigma} - 2\left[\frac{\dfrac{\Delta F}{\sigma + F}}{2 + \dfrac{\Delta F}{\sigma + F}}\right] = \frac{K}{\sigma}\,\Delta t \qquad [5\text{-}7]$$

Equation 5-7 is simplified into a quadratic whose solution is (8):

$$\Delta F = -\frac{(2F - K\,\Delta t)^2}{2} + \frac{[(2F - K\,\Delta t)^2 + 8K\,\Delta t(\sigma + F)]^{1/2}}{2} \qquad [5\text{-}8]$$

where ΔF is the change in infiltrated volume during time step t to t + Δt. The average infiltration rate, f_{ave}, is obtained by dividing ΔF by Δt, or:

$$f_{ave} = \frac{\Delta F}{\Delta t}, \qquad [5\text{-}9]$$

and compared to the current rainfall rate as entered by the user in the form of a hyetograph.

Based on the outcome of the comparison, the infiltrated volume is updated for the next time step by the potential calculated value if the rainfall rate, r, is greater than the average potential rainfall rate or by:

$$\Delta F = r \, \Delta t \,, \qquad [5\text{-}10]$$

if $r < f_{ave}$. In the former case, a rainfall excess intensity will exist during that Δt; the excess is given by:

$$e = r - f_{ave} \,.$$

In the later case e = 0. The program continues in this manner until the end of the storm thereby supplying the user with an excess rainfall rate histogram presented in tabular format.

III. Program Operation / Limitations

A number of methods for estimating the parameter values for the Green and Ampt model can be found in the literature. Average parameter values have been published for agricultural soils (15). Other methods applicable to other types soils are described in the references listed herein.

The program is applicable to homogeneous soil situations (i.e., single layer versus multilayer soils) and is limited to 300 rainfall increments in the hyetograph of a given problem. This limit should be more than adequate for all practical purposes but can be changed by adjusting the DIM statements for the appropriate variables in the source code. The program is completely menu-driven and prompts the user for all necessary input. A rainfall hyetograph may be input from a previously generated data file. A plot of time versus infiltration rate can be generated at the option of the user. A list of variables used in the program and comments explaining how the program works can be found in the source code.

IV. Example Problem

A flood control dam is planned for a portion of the Donkey Creek Basin. In order to size the structure properly the magnitude of expected flood events must be estimated. One event of interest is the 2-year, 6-hour storm for which the expected rainfall increments are:

Time (min)	Intensity (in/hr)
30	1.86
60	1.116
90	.558
120	.432
150	.432
180	.312
210	.312
240	.246
270	.246
300	.246
330	.246
360	.186

In order to derive a runoff hydrograph, the excess intensity for each of these hyetograph increments must be estimated. Values of .16 inches for average suction head and .3498 inches/hour for conductivity in the wetted zone are used for input to the Green-Ampt program.

```
*BRN A403/GREEN, R

This program uses the  Green - Ampt  infiltration  equation  to compute
incremental and cumulative  excess  rainfall and  infiltration volume.
The program implements the homogeneous soil  version  for  time varying
rainfall as represented by a  hyetograph.  Required  input includes the
average suction head and the conductivity in the wetted zone. The rain-
fall intensity  hyetograph  may  be  input  from the keyboard or from a
previously generated data file.

SELECT ONE:

     1 - BEGIN A NEW INFILTRATION ANALYSIS
     2 - END PROGRAM RUN

? 1

TITLE FOR OUTPUT? DONKEY CREEK BASIN

WHAT IS THE AVERAGE SUCTION HEAD (IN)? .16

WHAT IS THE HYDRAULIC CONDUCTIVITY IN WETTED ZONE (IN/HR)? .3498

HOW MANY RAINFALL INCREMENTS ARE IN HYETOGRAPH? 12

DO YOU WISH TO INPUT THE HYETOGRAPH FROM THE KEYBOARD OR FROM
A PREVIOUSLY GENERATED DATA FILE (1 OR 2) ?

     1 - KEYBOARD
     2 - FILE

? 1
```

```
ENTER TIME (MIN) AND RAINFALL INTENSITY (IN/HR) FOR EACH INCREMENT
(One increment per line with time & rainfall separated by comma)

INCREMENT NO.    1 ? 30,1.86
INCREMENT NO.    2 ? 60,1.116
INCREMENT NO.    3 ? 90,.558
INCREMENT NO.    4 ? 120,.432
INCREMENT NO.    5 ? 150,.432
INCREMENT NO.    6 ? 180,.312
INCREMENT NO.    7 ? 210,.312
INCREMENT NO.    8 ? 240,.246
INCREMENT NO.    9 ? 270,.246
INCREMENT NO.   10 ? 300,.246
INCREMENT NO.   11 ? 330,.246
INCREMENT NO.   12 ? 360,.186

   DONKEY CREEK BASIN

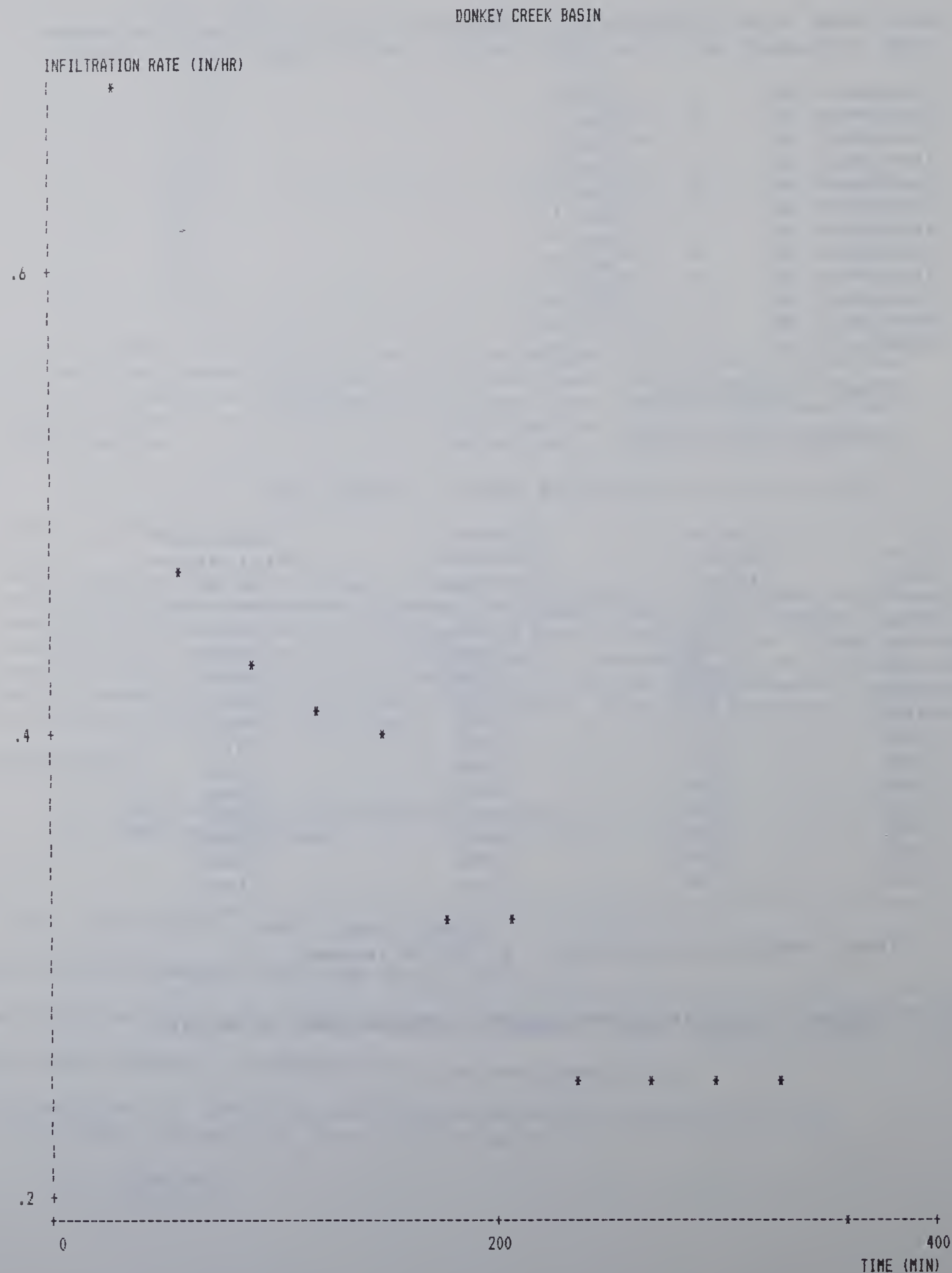
   Average Suction Head:  .16 inches

   Conductivity in the Wetted Zone:   .3498 in/hr
```

Time (min)	Storm Intensity (in/hr)	Excess Intensity (in/hr)	Rate of Infiltration (in/hr)
30	1.860	1.181	.679
60	1.116	.644	.472
90	.558	.126	.432
120	.432	.020	.412
150	.432	.031	.401
180	.312	.000	.312
210	.312	.000	.312
240	.246	.000	.246
270	.246	.000	.246
300	.246	.000	.246
330	.246	.000	.246
360	.186	.000	.186

```
   Total Infiltrated Volume:   2.095115 inches

DO YOU WISH TO PLOT INFILTRATION RATE VERSUS TIME (Y OR N)
? Y
```


DONKEY CREEK BASIN
INFILTRATION RATE (IN/HR)
.6
.4
.2
0
200
400
TIME (MIN)

```
SELECT ONE:

     1 - BEGIN A NEW INFILTRATION ANALYSIS
     2 - END PROGRAM RUN

? 2

ready
*
```

V. References

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6. SEDIMENT TRANSPORT ANALYSIS

I. Introduction

This program uses the Meyer-Peter, Muller equation (4) to compute the bedload transport rate for a given sediment size range. The program also computes the suspended sediment transport rate using a numerical integration of an approach developed by Einstein. Program output includes bedload and suspended load for each size range input as well as the total transport rate for all size ranges input (for a given rate of flow). Required input includes the Darcy-Weisbach friction factor, kinematic viscosity, the flow velocity, the width of flow, channel slope, and depth of flow.

II. Program Theory

The following discussion is taken from Eggert, et al. (2) upon which the program described herein is based.

The Meyer-Peter, Muller equation is a simple and commonly used bed load transport equation (6) which has the following form:

$$q_b = \frac{12.85}{\rho \quad Y_s} \left(T_E - T_C \right)^{1.5}, \qquad [6-1]$$

where,

$$T_C = {}_s(\delta_s - \delta) d_s, \text{ and} \qquad [6-2]$$

$$T_E = \frac{1}{8} \rho f_o V^2. \qquad [6-3]$$

In equations 6-1, 6-2, and 6-3, q_b is the bed load transport rate in cubic ft per second per ft of stream width, t_c is the critical tractive force, t_E is the boundry shear stress acting on the grain, is the density of water, T_s is the specific weight of the sediment, T is the specific weight of water, d_s is the size of the sediment fraction being analyzed, δ_s is a constant dependent upon flow conditions, f_o is the Darcy Weisbach friction factor, and V is the mean flow velocity obtained by dividing the discharge by the cross sectional area of the flow (Q/A). δ_s is assumed by the program to be 0.047 (2).

The sediment concentration profile which relates the sediment concentration with depth above the bed (3) can be written as:

$$\frac{C_\xi}{C_A} = \left[\frac{R-\xi}{\xi} \quad \frac{a'}{R-a'} \right]^{w}, \qquad [6-4]$$

in which C is the sediment concentration at a distance a' from the bed, C_A is the known concentration at a distance a' above the bed, and W is a parameter defined as:

$$W = \frac{V_s}{kU_*} . \quad [6\text{-}5]$$

In Equation 6-5, V_s is the settling velocity of the sediment particles, k is the Karman constant (assumed 0.4), and U_* is the shear velocity of the flow defined as:

$$U_* = \left[\frac{T_*}{\rho}\right]^{1/2} . \quad [6\text{-}6]$$

Note that,

$$T_* = \frac{1}{8} f \rho V^2 \quad [6\text{-}7]$$

where f is the overall Darcy-Weisbach resistance factor.

A logarithmic velocity profile is commonly adopted to describe velocity distribution in turbulent flows. A useful equation is:

$$\frac{u_\xi}{U_*} = B + 2.5 \ln \left[\frac{\xi}{\eta_s}\right] \quad [6\text{-}8]$$

in which u_ξ is the point mean velocity at the distance from the bed, B is a constant dependent on roughness, and $_s$ is the roughness height.

The integral of suspended load above the a' level in the flow is obtained by combining Equations 6-4 and 6-8:

$$q_s = \int_{a'}^{R} u_\xi C_\xi d\xi =$$

$$C_A U_* \int_{a'}^{R} \left[B + 2.5 \ln \left(\frac{\xi}{\eta_s}\right)\right] \left[\frac{R-\xi}{\xi} \quad \frac{a'}{R-a'}\right]^w d\xi . \quad [6\text{-}9]$$

Let

$$\alpha = \frac{\xi}{R} \quad [6\text{-}10]$$

and

$$G = \frac{a'}{R}. \qquad [6\text{-}11]$$

The equation becomes,

$$q_s = C_A U_* \int_{a'}^{R} \left[B + 2.5 \ln \left(\frac{\xi}{\eta_s} \right) \right] \left[\frac{1-\xi}{\xi} \; G - 1 \right]^{w} d\xi \,. \qquad [6\text{-}12]$$

According to Einstein ($\underline{3}$), the concentration near the "bed layer" C_A is related to the bed load transport rate q_b by the expression:

$$q_b = 11.6\, C_A U_* a' \qquad [6\text{-}13]$$

in which a' is defined as the thickness of the bed layer which is twice the size of the sediment, or $2d_s$.

The average flow velocity V is defined by the equation

$$V = \frac{\int_0^R u_\xi \; d\xi}{\int_0^R d\xi} \qquad [6\text{-}14]$$

Using Equation 6-8 yields,

$$\frac{V}{U_*} = B + 2.5 \ln \left(\frac{R}{\eta_s} \right) - 2.5 \qquad [6\text{-}15]$$

Einstein ($\underline{1}$), defined the two integrals in Equation 6-12 as,

$$I_1 = \int_G^1 \left(\frac{1-\alpha}{\alpha} \right)^{w} d\alpha \qquad [6\text{-}16]$$

and,

$$I_2 = \int_G^1 \left(\frac{1-\alpha}{\alpha} \right)^{w} \ln\alpha \;\; d\alpha \qquad [6\text{-}17]$$

The integrals I_1 and I_2 cannot be integrated in closed form for most values of W so a numerical integration is necessary. A efficient numerical method of determining I_1 and I_2 was developed by Li ($\underline{2}$).

The substitution of Equations 6-13, 6-14, 6-15, 6-16, and 6-17 into Equation 6-12 yields:

$$q_s = \frac{q_b}{11.6} \; \frac{G^{w-1}}{\left(1-G\right)^{w}} \left[\left(\frac{V}{U_*} + 2.5\right) I_1 + 2.5\, I_2\right]. \quad [6\text{-}18]$$

The total load per unit width of the channel is:

$$q_T = q_b + q_s. \quad [6\text{-}19]$$

III. Program Operations / Limitations

Applied to stable water courses the Meyer-Peter, Muller formula gives satisfactory estimates of sediment transport. But when the slope becomes larger than 0.00 there may be large differences between computed and observed values. The precision of this formula is also influenced by the size of the bed material. It gives satisfactory results for fine and medium sand bed channels. However, significant discrpancies may occur when estimating sediment discharge in coarse bed material channels (5).

The program allows as many sediment size ranges as desired to be run for any given analysis. It completly menu driven and prompts the user for all necessary input. Output is in a tabular format. A complete listing of the variables used in the program as well as comments describing its operation can be found in the source code.

IV. Example Problem

Due to the presence of a large surface mine, the main channel of Rawhide Creek is to be temporarily routed through a diversion excavated in a silty-sandy aeolian deposit. It is desired to estimate the bedload transport rate of this material at the expected mean flow in order to help determine the stability of the channel.

*BRN A403/MPM, R

This program uses the Meyer-Peter, Muller equation to compute the bedload transport rate for a given sediment size range. The program also computes the suspended sediment transport rate using a numerical integration of an approach developed by Einstein. Program output includes bedload and suspended load for each size range input as well as the total transport rate for all size ranges input (for a given rate of flow). Required input includes the Darcy-Weisbach friction factor, kinematic viscosity, the flow velocity, the width of flow,

channel slope, and depth of flow.

```
SELECT THE PROCEDURE DESIRED:

   1 - SEDIMENT TRANSPORT ANALYSIS
   2 - END PROGRAM RUN

? 1

TITLE FOR OUTPUT ? RAWHIDE CREEK BASIN

DARCY-WEISBACH FRICTION FACTOR ? .025

KINEMATIC VISCOSITY (sq ft/sec) ? .0000111

STREAM WIDTH (ft) ? 8

VELOCITY (ft/sec) ? 2.89

SLOPE (rise/run) ? .0017

HYDRAULIC DEPTH (ft) ? .51

HOW MANY SIZE RANGES DO YOU WISH TO EVALUATE ? 1

GEOMETRIC MEAN PARTICLE SIZE (ft) FOR SIZE RANGE NO.  1 ? .000623

PROBABILITY FOR SIZE RANGE NO.  1 ? 1

RAWHIDE CREEK BASIN

Flow Velocity           =  2.89 ft/sec
Top Width               =     8 ft
Flow Depth              =   .51 ft
Slope                   =    .0017 ft/ft
Darcy-Weisbach Factor =  .025
Kinematic Viscosity     =  1.11000e-05    sq ft/sec
```

SIZE (ft)	PROB	(cfs) -- BEDLOAD --	(lb/sec)	(cfs) -- SUSPENDED --	(lb/sec)
.000623	1.00	.00463	.76596	.01857	3.07063
TOTALS >		.00463	.76596	.01857	3.07063

```
SELECT THE PROCEDURE DESIRED:

   1 - SEDIMENT TRANSPORT ANALYSIS
   2 - END PROGRAM

? 2

ready
*
```

V. References

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7. DETENTION POND ANALYSIS

I. Introduction

Urbanization of a watershed increases the percent of impermeable surface and changes drainage patterns resulting in increases in runoff volumes and peak discharge rates. One method for counter-acting this effect is to construct detention ponds within the basin to limit peak flow rates from developed areas to those which occurred prior to development (1). This program follows the method described in SCS Technical Release No. 55 entitled, *Urban Hydrology for Small Watersheds* (2) for estimating the volume of required detention storage necessary to achieve this goal.

II. Program Theory

TR-55 provides two methods for determining required detention pond storage. The first method, the inflow-outflow-storage method, is recommended when the desired outflow rate from the pond is less than 150 csm (cfs per square mile of drainage area) for a weir-type discharge structure and less than 300 csm for a pipe discharge. The second method, the volume-rate method, is recommended for outflow rates above these maximums. The later method is implemented in this program.

The volume-rate method utilizes a curve which relates the ratio of the volume of storage and volume of runoff (V_S/V_R) to the ratio of peak rate of outflow to peak rate of inflow (Q_O/Q_I). The curve was developed using known relationships involving a Type II storm distribution applied to a 24-hour rainfall and assumes that the volume available for temporary storage is small relative to the expected runoff volume.

Normally, to apply the volume-rate method to derive a required storage volume, the user must estimate the runoff volume and peak discharge rate under post development conditions for a given 24-hour storm. Using the ratio of Q_O (the rate of peak discharge desired from the pond after development) to Q_I (estimated post-development rate of inflow) the ratio of required volume of storage to estimated post-development runoff volume can be derived from the volume-rate curve. Since:

$$\frac{V_S}{V_O} = \text{ratio} \qquad [7\text{-}1]$$

then,

$$V_S = V_O\ (\text{ratio}). \qquad [7\text{-}2]$$

In order to avoid the need to use the volume-rate curve, the program uses the following polynomial approximation:

$$\frac{V_s}{V_o} = \left[1 - 2\frac{Q_o}{Q_T} + 1.8\left(\frac{Q_o}{Q_T}\right)^2 - 0.8\left(\frac{Q_o}{Q_T}\right)^3\right] \qquad [7\text{-}3]$$

The program also provides the option to compute the estimated volume of runoff using the SCS curve number method. The volume of runoff depends upon the volume of precipitation and the volume retention due to infiltration, surface storage, and other factors. Retention is defined as the difference between the volume of precipitation and the volume of runoff. The SCS method assumes that a certain volume of precipitation at the beginning of the storm, called the initial abstraction, will not appear as runoff. These relationships are inherent in the following equation:

$$\frac{F}{S} = \frac{Q}{P - I_A} \qquad [7\text{-}4]$$

where,

F = actual retention,
S = potential maximum retention,
Q = volume of runoff,
P = volume of precipitation, and
I_A = initial abstraction.

The actual retention is therefore:

$$F = (P - I_A) - Q. \qquad [7\text{-}5]$$

Substituting Equation 7-4 into Equation 7-5 yields:

$$\frac{(P - I_A) - Q}{S} = \frac{Q}{P - I_A}, \qquad [7\text{-}6]$$

and solving for Q yields,

$$Q = \frac{(P-I_A)^2}{(P - I_A) + S} \qquad [7\text{-}7]$$

Empirical data suggests that:

$$I_A = 0.2S, \qquad [7\text{-}8]$$

and substituting Equation 7-8 into 7-7 yields,

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} . \qquad [7-9]$$

Empirical data indicates that:

$$S = \frac{1000}{CN} - 10, \qquad [7-10]$$

where CN = runoff curve number for the basin under study and is a an index of soil type, land use, agricultural land treatment class, hydrologic condition, and antecedent moisture condition. Methods for choosing CN values are discussed in a number of widely distributed publications including, *The SCS National Engineering Handbook, Section 4, Hydrology* (3), and *Design of Small Dams* (2).

III. Program Operation / Limitations

TR-55 states that in instances where runoff curve numbers are less than 65 in combination with short times of concentration, V_s/V_o will be up to 25 percent too high. Runoff curve numbers over 85 with long times of concentration cause V_s/V_o values to be up to 25 percent too low. For weir flow structures with desired outflow rates less than 150 csm or pipe flow structures with desired outflow rates of less than 300 csm, the graphical inflow-outflow-storage method in TR-55 should be used.

The program accepts a design storm rainfall amount in inches which is then converted to a volume by applying the watershed drainage area. Runoff amounts which are input directly in inches are converted in the same manner. As the following example illustrates, a required detention pond storage volume can be computed by entering the desired outflow rate, or the resulting outflow rate can be computed given an available storage volume. The program is completely menu-driven and prompts the user for all input. A list of the variables used in the program and comments describing its operation can be found in the source code.

IV. Example Problem

A new housing development has just been completed in the Donkey Creek basin. Is desired that a storm runoff retention pond be constructed to maintain downstream flows at the same rate as pre-development. Prior to development the basin curve number was estimated at 60. After development the curve number has increased to 80. The drainage area above the proposed detention pond is 30 acres. The pond is to be designed for the 10-year, 24-hour storm for which the precipitation amount is 4 inches. Post development is to be kept to 9 cfs and the design storm inflow rate is estimated at 38 cfs. What size pond is required ? If 2.3 acre-ft

is available for the pond, what can the expected outflow be reduced to ?

*BRN A403/POND, R

This program calculates the pond volume required to detain the excess runoff occuring because of a change in basin runoff conditions. Detention pond volume is calculated using estimated peak inflow, desired peak outflow, and the expected excess runoff volume. Excess runoff volume can either be input directly (pre- and post rainfall excess) or can be calculated using SCS methods (pre- and post Curve Numbers). The program will also calculate expected peak outflow from a detention pond given rainfall excess, storage capacity, and peak inflow. To begin the program select one of the following options:

```
            1 - COMPUTE POND DETENTION VOLUME
            2 - COMPUTE EXPECTED PEAK POND OUTFLOW
            3 - END PROGRAM RUN

? 1

TITLE FOR OUTPUT? DONKEY CREEK POND

INDICATE HOW YOU WISH TO INPUTE RAINFALL EXCESSES:

       1 - ENTER RAINFALL EXCESSES DIRECTLY
       2 - CALCULATE EXCESSES FROM SCS CURVE NUMBERS

? 2

ENTER CURVE NUMBER PREVIOUS TO CHANGE IN WATERSHED:
? 60
ENTER CURVE NUMBER AFTER CHANGE IN WATERSHED:
? 80
ENTER 24-HOUR RAINFALL FOR DESIRED DESIGN STORM (IN):
? 4

WATERSHED DRAINAGE AREA (ACRES)? 30

ESTIMATED POND PEAK INFLOW RATE (CFS)? 38

DESIRED POND PEAK OUTFLOW RATE (CFS)? 9

DONKEY CREEK POND

INCREASED RAINFALL EXCESS =     1.2798 IN
DRAINAGE AREA =                30.0000 ACRES
ESTIMATED PEAK INFLOW =        38.0000 CFS
DESIRED PEAK OUTFLOW =          9.0000 CFS

POND STORAGE REQUIRED =         1.9729 ACRE-FT
```

```
          1 - COMPUTE POND DETENTION VOLUME
          2 - COMPUTE EXPECTED PEAK POND OUTFLOW
          3 - END PROGRAM RUN

? 2

TITLE FOR OUTPUT? DONKEY CREEK POND

INDICATE HOW YOU WISH TO INPUTE RAINFALL EXCESSES:

      1 - ENTER RAINFALL EXCESSES DIRECTLY
      2 - CALCULATE EXCESSES FROM SCS CURVE NUMBERS

? 2

ENTER CURVE NUMBER PREVIOUS TO CHANGE IN WATERSHED:
? 60
ENTER CURVE NUMBER AFTER CHANGE IN WATERSHED:
? 80
ENTER 24-HOUR RAINFALL FOR DESIRED DESIGN STORM (IN):
? 4

WATERSHED DRAINAGE AREA (ACRES)? 30

AVAILABLE POND STORAGE (ACRE-FT)? 2.3

EXPECTED INFLOW (CFS)? 38

DONKEY CREEK POND

INCREASED RAINFALL EXCESS =     1.2798 IN
DRAINAGE AREA =                30.0000 ACRES
ESTIMATED PEAK INFLOW =        38.0000 CFS
POND STORAGE AVAILABLE =        2.3000 ACRE-FT

ESTIMATED PEAK OUTFLOW =        6.4320 CFS

          1 - COMPUTE POND DETENTION VOLUME
          2 - COMPUTE EXPECTED PEAK POND OUTFLOW
          3 - END PROGRAM RUN

? 3


ready
*
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V. References

1. McCuen, R.H., 1982. A Guide to Hydrologic Analysis Using SCS Methods. Prentice-Hall, Inc., Englewood Cliffs, N.J.

2. U.S. Bureau of Reclamation, 1977. Design of Small Dams. U.S. Government Printing Office, Washington, D.C.

3. U.S. Soil Conservation Service, 1972. National Engineering Handbook, Section 4, Hydrology. National Technical Information Service, Springfield, Virginia.

4. U.S. Soil Conservation Service, 1975. TR-55: Urban Hydrology for Small Watersheds. Technical Release No. 55, U.S. Gov. Printing Office, Washington, D.C.